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CR-119127

AN INTEGRATED STUDY OF EARTH RESOURCES

IN THE STATE OF CALIFORNIA

USING REMOTE SENSING TECHNIQUES

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(E76-10019) AN INTEGRATED STUDY OF EARTH
RESOURCES IN THE STATE OF CALIFORNIA USING
REMOTE SENSING TECHNIQUES Annual Progress
Report (California Univ.) 619 p HC \$15.25

N76-10551

Unclass

CSSL 08F G3/43 00019

A report of work done by scientists
of 4 campuses of the University of
California (Davis, Berkeley, Santa
Barbara and Riverside) under NASA
Grant NGL 05-003-404

Annual Progress Report

1 May 1975

Space Sciences Laboratory Series 16, Issue 34

UNIVERSITY OF CALIFORNIA, BERKELEY

AN INTEGRATED STUDY OF EARTH RESOURCES
IN THE STATE OF CALIFORNIA
USING REMOTE SENSING TECHNIQUES

Principal Investigator:

Robert N. Colwell

A report of work done by scientists
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Annual Progress Report
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University of California, Berkeley

CHAPTER 1

INTRODUCTION

Principal Investigator: Robert N. Solwell

TABLE OF CONTENTS

- Chapter 1 Introduction
Robert N. Colwell, Principal Investigator
- Chapter 2 Water Supply Studies in Northern California
Introduction
Randall W. Thomas (Berkeley Campus)
- Algazi-Burgy Group Water Supply Studies (a)
V. Ralph Algazi (Davis and Berkeley Campuses) and
Robert Burgy (Davis Campus)
- Remote Sensing-Aided Procedures for Water Yield
Estimation (b)
Randall W. Thomas (Berkeley Campus)
- Chapter 3 Water Demand Studies in Central California
John E. Estes (Santa Barbara Campus)
- Chapter 4 Use of Remote Sensing to Determine the Water Demands of the
Upper Santa Ana River Drainage Basin
Leonard W. Bowden (Riverside Campus)
- Chapter 5 Socio-Economic Impact of Remote Sensing Water Supply Data
Ida R. Hoos (Berkeley Campus)
- Chapter 6 A Comparative Cost-Effectiveness Analysis of Existing and ERTS-
Aided Snow Water Content Estimation Systems
Randall W. Thomas and James M. Sharp (Berkeley Campus)
- Chapter 7 ERTS as an Aid in Timber Volume Inventory
James D. Nichols, et al. (Berkeley Campus)
- Chapter 8 Cost-Effectiveness Comparison of Existing and ERTS-Based
Total Timber Resources Inventory Systems
James D. Nichols, et al. (Berkeley Campus)
- Chapter 9 Special Studies
No. 1 - Atmospheric Effects in Image Transfer
K. L. Coulson and R. L. Walraven (Davis Campus)
No. 2 - The Potential Usefulness of Earth Resources
Technology Satellites in Relation to the Manage-
ment of Earth Resources and the Preservation
of Man's Environment
Co-Investigator: Robert N. Colwell, Berkeley Campus

TABLE OF CONTENTS (continued)

Chapter 9 Special Studies (continued)

- No. 3 - Statement Before the Subcommittee on Space
Science and Applications of the Committee
on Science and Astronautics, U.S. House of
Representatives, Ninety-third Congress,
Second Session
Co-Investigator: Robert N. Colwell, Berkeley Campus
- No. 4 - Input Quality Encoding of Multispectral Data
Co-Investigator: V. Ralph Algazi
- No. 5 - Utilization and Assessment of Remote Sensing Data
Co-Investigator: Ida R. Hoos
- No. 6 - Statement Before the Interior Subcommittee of the
Appropriations Committee, U.S. Senate, Ninety
Fourth Congress
Co-Investigator: Robert N. Colwell, Berkeley Campus

Chapter 10 Summary

Robert N. Colwell, Principal Investigator

Chapter 1

INTRODUCTION

Robert N. Colwell

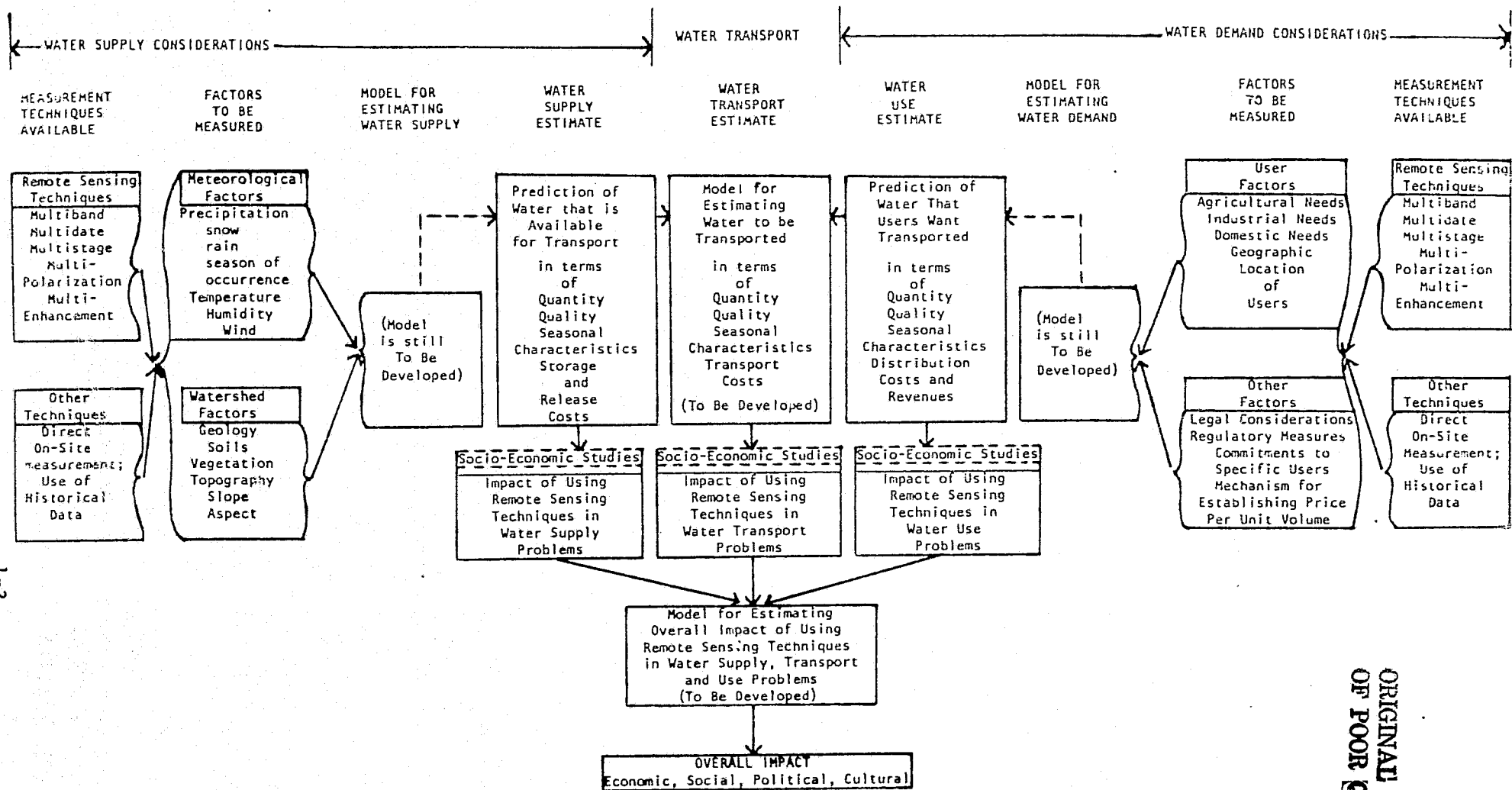
There is a rapidly increasing need in California, as in many other parts of the world, for wise management of such earth resources as agricultural crops, timber, forage, water, minerals, soils, fish, wild-life and oceanographic and atmospheric resources. An important first step leading to such management is that of obtaining accurate inventories of these resources quickly, economically and at suitably frequent intervals. Remote sensing from aircraft and spacecraft is proving to be of great value in the making of these inventories. In this progress report on work which our 4-campus group has done during the past year under NASA Grant NGL-05-003-404, numerous examples are given of the uses made of such sensing as an aid to resource inventory in California.

All of the remote sensing studies reported upon in this progress report had a 2-fold objective: (1) to provide improved information on the nature and extent of California's earth resources, thereby facilitating the management of those resources, and (2) to use the state of California as a "test site" in which to develop means for identifying from remote sensing data various kinds of earth resource features, thereby permitting the same or similar features to be identified in other parts of the world as well. This latter consideration is of such importance as to merit some elaboration.

Of all the 50 states, California has proved in many respects to be the most favorable test site in which to conduct integrated remote sensing research. Specifically: (a) California exhibits an unusually great range in both climatic and topographic conditions and also in its latitudinal and elevational limits. As a result it also exhibits an unusually great range in the vegetation types, both natural and agricultural, which it supports, thereby ensuring that this particular state constitutes a very favorable test site for those interested in remote sensing as an aid to the inventory of timber, forage, and agricultural resources. (b) The unusually great wealth of petroleum and mineral resources to be found and managed in California, combined with its very significant faulting and its geothermal activity, ensure that it is a favorable test site for those interested in remote sensing as an aid to the inventory and management of geologic resources, (c) The unusually

high production of water supplies in some parts of the state, combined with the unusually great water demands generated in other parts of the state (e.g. by agriculturists, industrialists and urbanites) ensure that California is an almost ideal test site for those interested in the inventory and management of water resources; (d) Although California's atmosphere is notably cloud-free during most of each year's growing season (thereby ensuring a remarkably unobstructed look at the face of California from remote sensing aircraft and spacecraft) this state also must admit to having some of the most smog-infested areas on the surface of the earth. As a result, California is an ideal test site for those concerned with the use of remote sensing to monitor and manage atmospheric resources; (e) California's thousand-mile coastline exhibits conditions ranging from the most pristine to the most polluted; more than 80 per cent of the state's population dwells within the coastal fringe; with some of its marine organisms flourishing while others are on the verge of extinction, California certainly constitutes a very favorably test site for those concerned with coastal and oceanographic (marine) resources. (f) As one of the leading producers and consumers of energy (whether it be petroleum-derived, hydro-electric or geothermal) and with cloud-free deserts, this state constitutes an understandably attractive test site for those interested in remote sensing as an aid to the inventory and management of energy resources. (g) Finally, as a state that is unusually attractive to those having leisure time, and exhibiting intense interests that range from golfing to scuba diving, from hiking to motoring, from sailing to soaring, from big game hunting to deep sea fishing, from preserving wilderness areas as a challenge to the young and vigorous to converting them into comfortable retirement communities for the aged and flabby, certainly California constitutes an ideal test site for those concerned with the inventory and management of recreational resources.

During the period covered by this progress report, research efforts under our integrated multi-campus study have continued to be concentrated along the lines set forth, at NASA's request, in our statement of 30 September, 1973. Consequently, the major part of our work during this reporting period has dealt with California's water resources. The block diagram of Figure 1-1 and the milestones of Figure 1-2 provide a good overview of both the concept embodied in this study and the activities being engaged in by the various participants. As indicated by both of those figures, our integrated study of California's water resources continues to concern itself primarily with the usefulness of remote sensing in relation to two categories of problems: (1) those pertaining



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FIGURE 1.1 Block diagram indicating the factors which relate to water supply, water transport, water use and water impact. For a discussion of the proposed remote sensing studies in relation to this diagram, see text.

Work Subtask	Investigators	Period of Performance											
		Current Funding Year						Next Funding Year					
		M	J	J	A	S	O	N	D	J	F	M	A
1. Continue Water Supply Model Definition and Performance Documentation	Algazi-Burgy (1) RSRP (2)												
2. Sensitivity Analysis for Critical Parameters in Water Supply Models	RSRP (1) Algazi-Burgy (2)												
3. Develop and Test Remote Sensing Techniques for water supply	RSRP (1) Algazi (2)												
4. Determine Costs of Information-Gathering Using Conventional and Remote Sensing-Aided Methods	RSRP (1) Hoos-Churchman (2) Algazi-Burgy (2)												
5. Compare Remote Sensing Techniques for water supply with Conventional Ones. Draw Conclusions Regarding Cost-Effectiveness	Hoos-Churchman (1) RSRP (2)												
6. Analyze Cost-Benefit Impact on Society Resulting from Changes in Water Supply Information Due to Application of Remote Sensing Techniques	Hoos-Churchman (1) RSRP (2)												
7. Determine critical parameters in water demand models	Estes (1) Bowden (2) Algazi-Burgy (2)												
8. Analyze economic impact resulting from changes in water demand information	Bowden (1) Estes (1) Hoos-Churchman (2)												
9. Compute economic effects of changes in estimation of critical water demand parameters	Bowden (1) Estes (1) Hoos-Churchman (2)												
10. Evaluate and test remote sensing techniques in relation to water demand	Bowden (1) Estes (1) RSRP (2)												
11. Determine costs of water demand information-gathering using conventional methods	Bowden (1) Estes (2)												
12. Compare water demand remote sensing techniques with conventional methods	Bowden (1) Estes (2) RSRP (2) Hoos-Churchman (2)												
13. Estimate potential impact of using remote sensing techniques in water demand problems	Bowden (1) Estes (1) RSRP (2) Hoos-Churchman (2) Algazi-Burgy (2)												

FIGURE 1.2 Chronological Plan for the Assessment of Water Supply and Water Demand by Means of Remote Sensing.
(1) Indicates primary responsibility; (2) Indicates secondary responsibility.

to water supply (dealt with primarily by personnel of the Davis and Berkeley campuses as reported upon in Chapters 2a and 2b, respectively); and (2) those pertaining to water demand (dealt with primarily by personnel of the Santa Barbara and Riverside campuses as reported upon in Chapters 3 and 4, respectively).

Opportunities which we are exploiting to the fullest in our attempt to achieve true integration of this multicampus project stem from the following fact that repeatedly manifests itself: many of the techniques and methodologies developed by those of our group who are concerned with water supply problems can, with only slight modification, be used by those of us who are concerned with water demand problems, and vice versa. Thus, for example, much of the information contained in Chapters 5 and 6 relative to cost-effectiveness methodologies and the techniques for making truly meaningful cost-benefit analyses deal primarily with problems pertaining to water supply. As indicated in those chapters, however, little modification would be needed to apply these same methodologies and techniques to problems of water demand. Similarly, the work being reported upon in Special Study No. 1 of Chapter 9 (viz. the work of Coulson and Walraven of the Davis Campus on Atmospheric effects in image transfer) is of very great potential significance in relation to image analysis problems generally, whether they deal with water supply, water demand, or virtually any other kind of problem confronting those who wish to use remote sensing to maximum advantage in relation to the management of earth resources.

With further reference to Chapter 9, two other special reports (numbered 2 and 3) are included. These summarize certain findings under this integrated project that the author considered would be relevant to deliberations being held by the U.S. Senate and House committees, respectively, relative to the future of NASA's Earth Resources Survey program. The strength of both of those reports was significantly increased by our being able to draw upon the findings of all of the NASA-funded participants in this multicampus integrated study. The same can be said also for Special Report Number 6 of Chapter 9 which consists of a statement made by one of our co-investigators before the Interior Subcommittee of the Senate Appropriations Committee. Also in Chapter 9 is a special study (numbered 5) dealing with the utilization and assessment of remote sensing data. This special study was performed by our Social Sciences group, as part of our integrated study, and deals with the interface between remote sensing technology and the society which it seeks to serve. The study deals largely, but not exclusively, with California's water resources.

There has been one notable exception to the previously stated emphasis of our project on water resources. The exception, made at NASA's request, has resulted from questions raised by U.S. Forest Service officials regarding the usefulness of ERTS-type data as an aid to forest inventory. In this regard, Mr. Frank Zarb of the federal Office of Management and Budget, Executive Office of the President, in his testimony before the Senate Committee on Science and Astronautics said:

"The Forest Service has stated that there is as yet no demonstrable need in forest inventory, the major area of benefit in forestry, for frequent acquisition of the relatively low resolution produced by ERTS"^{**}.

Research efforts^{**} by our group to test the validity of this assertion are reported separately, in Chapters 7 and 8 of this progress report. Suffice it to say here that, as a result of these research efforts, we find ourselves in substantial disagreement with the assertion quoted above. Consequently, during the present reporting period, we have engaged in a series of discussions with senior Forest Service officials in an effort to reconcile our findings with theirs.

Parenthetically it should be noted that both the Chief of the U.S. Forest Service, Dr. John McGuire and the Assistant Chief for Research, Dr. Dickerman were among those present at the FAO World Forestry Congress in Rome, Italy on May 20, 1974 when our project's principal investigator gave a "Pro-ERTS" presentation entitled "Remote Sensing and Proximal Sensing as Aids in the Making of Forest Resource Inventories". Leading forestry officials from the 50 other leading countries, in terms of forest resources, also were present. Reactions to this "Inagural address", as expressed by the Chief of the U.S. Forest Service and his counterpart in each of several other countries, were generally very favorable, indeed.

Chapter 10 contains a brief summary of our activities and findings during the present reporting period and indicates the direction which our group, guided by various NASA monitors, proposes to take in the future, consistent with the block diagram of Figure 1-1 and the milestone chart of Figure 1-2.

* Except for quotations such as this, and cross-references to them, our present progress report uses the new term "LANDSAT", rather than the corresponding old term, "ERTS".

** Technique development and testing for the ERTS-aided timber inventory procedures evaluated for cost-effectiveness were performed under Remote Sensing Research Program ERTS-1 studies funded by NASA contract no. NAS 5-21827, Task III, Investigation #317C. The comparative cost-effectiveness analyses described in this report were performed under this NASA grant's funding.

During the period covered by this report we have received guidance from an unusually large number of NASA personnel including 4 from the NASA Ames Research Center. To a very significant degree the contents of this Progress Report reflect advice received periodically from Mr. Leonard Jaffe of NASA's Office of Applications. It was Mr. Jaffe who provided the directives that led to our present emphasis on California's Water Resources and who presided at briefings which we gave in Berkeley on June 20, 1974 and in Washington D. C. on December 9, 1974.

Dr. Al Stratton, the new NASA monitor of our project has found it possible to attend briefings which our group has given during the period covered by this report, whether in California or at NASA Headquarters in Washington D. C. and has ably participated in those briefings. During this same period he also has visited most of our research spaces on the Riverside, Santa Barbara, Berkeley and Davis campuses, thereby acquiring an unusually good grasp of our research capabilities and limitations and an appreciation of the remote sensing equipment, facilities and professional expertise available to us.

Also, during the period covered by this report, on three timely occasions, (October 3, November 8 and December 7, 1974), Dr. Peter Castruccio in his capacity as a special consultant for NASA relative to our project has made himself available in the Washington D. C. area for detailed discussions with our project's principal investigator. These discussions have done much to broaden the perspective of our group, to identify the "drivers" in relation to water supply and demand problems in various geographic areas, and to increase the applicability of our findings to water resource management in other parts of the world.

Through timely consultations with both Dr. Frank Hanzing and Dr. Joe Vitale of NASA's Office of University Affairs, (co-sponsors of our project) we again have received valuable and constructive criticism and with it the opportunity to acquaint two important groups with the results of our efforts to date under this integrated study. The first of these groups was the American Association of Engineering Educators at its annual meeting in June, 1974 at Rensselaer Polytechnic University in New York; the second was the group assembled in Boulder Colorado in July, 1974 under the chairmanship of Dr. Jack Ives of the Institute for Alpine and Arctic Research to discuss problems associated with "Man and the Biosphere". In both instances a presentation of our work was given by the principal investigator and was followed by constructive criticism from conference attendees.

With further reference to Dr. Castruccio's involvement in our project, special mention is made here of his effective role in working with personnel of our Social Sciences group. Largely because of his participation, care has been taken by members of our Social Sciences Group to link their work more directly than heretofore into other phases of the joint research effort,

as performed by our remote sensing specialists. In responding to the need for this linkage our social scientists now are able to state:

"Essentially, we all are engaged in investigating the ways in which satellite - derived and other technologically advanced imagery can be utilized in the management of natural resources. The function of the Social Sciences Group is to ascertain ways in which remote sensing data can enter into the decision making process, their costs and effectiveness, and their potential impact and implications."

Our Social Sciences Group also asserts: "With the California Water Project as our primary, but not exclusive, focus, we try to develop insights into the very complicated web of factors impinging on the management of resources in order to learn how new sources of information can be accommodated, by whom, and for what purpose. It is patently clear that these decisions do not take place in a technological, economic, political and social vacuum; decisions regarding resources take place in a real-life, rapidly changing environment. Our task is, therefore, to map the social landscape, the better to learn where, how, and to what effect new sources of information can prove their mettle."

In recent years it has become increasingly apparent to our project's remote sensing scientists that a lack of "technology acceptance" by resource managers and others very often constituted a major deterrent to the achieving of something of practical value from our research. It therefore became apparent that the most significant of our own findings should be integrated with those of our remote sensing colleagues elsewhere, preferably through the publication of some kind of definitive remote sensing "manual". We all recognized that if such a document, well illustrated, were to be prepared under auspices of some professional group of high repute, (such as the American Society of Photogrammetry), and made quite generally available in highly comprehensible form, much would be done to achieve the necessary technology acceptance.

Such an effort also would do much to stem the criticism that we sometimes have heard to the effect that many of our NASA-funded research findings remained buried in progress reports, never to be seen by resource managers and other potential users of modern remote sensing technology.

Pursuant to this thought, we will conclude this introductory chapter by inviting attention to the unusually substantial contribution which those involved in our integrated study have been making to the "Manual of Remote Sensing" which currently is nearing completion under auspices of the

American Society of Photogrammetry. Collectively speaking, our contribution to this first definitive and authoritative treatment of remote sensing ranges from co-editorship of the entire Manual, through authorship of its Introductory chapter and co-authorship of several other chapters, to the menial tasks of providing large amounts of illustrative material and of proof-reading manuscripts. Once that Manual has been published, it should be apparent to any interested reader, as it now is to us, that our findings to date under this integrated study provide some of the most compelling evidence, both qualitative and quantitative, for the adoption by resource managers of modern remote sensing techniques.

CHAPTER 2

WATER SUPPLY STUDIES IN NORTHERN CALIFORNIA

Introduction

Co-Investigator: Randall W. Thomas, Berkeley Campus

Algazi-Burgy Group Water Supply Studies (a)

Co-Investigators: V. Ralph Algazi, Davis and
Berkeley Campuses and Robert
Burgy, Davis Campus

Remote Sensing-Aided Procedures for Water Yield Estimation (b)

Co-Investigator: Randall W. Thomas, Berkeley Campus

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CHAPTER 2

WATER SUPPLY STUDIES IN NORTHERN CALIFORNIA

The Remote Sensing Research Program (Berkeley), the Algazi Group (Davis, Berkeley) and the Hoos-Churchman Social Sciences Group (Berkeley) are presently involved in the NASA Grant water supply and remote sensing application studies in Northern California. Continuing analysis of hydrologic model structure, inputs, and performance is being conducted by the former two groups. Performance is being documented with respect to "conventional" and to "conventional plus remote sensing" data inputs. Both the Remote Sensing Research Program (RSRP) and the Hoos-Churchman Group are quantifying costs and benefits associated with current and potential remote sensing-aided hydrological model applications.

This work is set in perspective by a continuing analysis of the California Water Project as a system from the standpoint of both physical and economic phenomena. It is apparent from the current analysis of future product importance in the California Water Project, that issues other than water quantity, such as water quality and power generation, will become increasingly significant. The water supply investigating groups funded under the present grant are moving to investigate the feasibility of performing remote sensing applicability studies involving these other water-related parameters,

The RSRP, Algazi, and Hoos-Churchman groups are conducting remote sensing water supply application studies in an integrated manner. Figure 2.1 gives the time schedule by subtask for this effort. It should be noted with reference to this figure that studies documenting remote sensing economic impact are now significantly under way. Cost-effectiveness methodologies are cited in Chapter 2b and are documented in Chapters 6, 7, and 8. Preparation for cost-benefit analysis, requiring much data on technique development as well as a wide social spectrum of cost documentation, is cited in Chapters 5, 6, and 8.

The progress report of the Social Science Group is given in Chapter 5, while that of the Algazi and RSRP groups is reported here in Chapter 2. For organizational and clarity purposes, Chapter 2 is broken into two parts. The first, Chapter 2a, is devoted to the Algazi Group report, and the second, Chapter 2b, consists of RSRP work relating to remote sensing-aided water variable estimation. Chapter 6 reports on a cost-effectiveness analysis for a remote sensing-aided snow water content estimation system which is based on work reported in Chapter 2b.

FIGURE 2.1 - CHRONOLOGICAL PLAN FOR THE PERFORMANCE OF WATER SUPPLY STUDIES

Work Subtask	Investigators	Period of Performance																							
		Current Funding Year												Next Funding Year*											
		M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
1. Continued Water Model Definition and Performance Documentation	Algazi-Burgy RSRP																								
2. Sensitivity Analysis for Critical Parameters in Water Supply Models	Algazi-Burgy RSRP																								
3. Develop and Test Remote Sensing Techniques	RSRP Algazi																								
4. Determine Costs of Information-Gathering Using Conventional and Remote Sensing-Aided Methods	Hoos-Churchman RSRP Algazi-Burgy																								
5. Compare Remote Sensing Techniques with Conventional Ones. Draw Conclusions Regarding Cost-Effectiveness	Hoos-Churchman RSRP																								
6. Analyze Cost-Benefit Impact on Society Resulting from Changes in Water Supply Information Due to Application of Remote Sensing Techniques	Hoos-Churchman RSRP																								

* Beginning on 1 May, 1975.

TABLE OF CONTENTS

		<u>Page</u>
2.0a	Introduction	2a-1
2.1a	Overview of the California Water Project - An Update (1,2,3,4)	2a-1
2.2a	Analysis and Study of Watershed Models Amenable to Remote Sensing Inputs	2a-5
2.3a	Application of Digital Processing Techniques in Remote Sensing	2a-23
2.4a	Digital Image Processing Techniques Development	2a-24
2.5a	Publications and Technical Presentations	2a-25
APPENDIX I:	Input Quality Encoding of Multispectral Data	2a-29
APPENDIX II:	Some Remote Sensing Applications of Digital Signal Processing	
APPENDIX III:	Separation of Man-Made and Natural Patterns in High-Altitude Imagery of Agricultural areas	2a-41

CHAPTER 2(a)

Co-Investigator: R. Algazi

Contributors: J. Amorcho, M. Suk, J. Stewart,
B. Romberger

2.0a Introduction

After the meeting of the Remote Sensing Project of the University of California with NASA personnel in September 1973, a significant change of emphasis occurred in the work of the group in response to NASA's wishes. This new emphasis is aimed at increasing the applicability, the usefulness and the economic import of our work in the short term as well as in the long run. Since the focus of the project, up to this date, is in the application of remote sensing to water resources, a considerable part of our time in the past year has been devoted to the elucidation of the California Water Project, taken as an example, both of a complex system and in some of its most pertinent components. In this work we have tried to proceed from a general understanding to specific questions. In addition to this systems engineering and modeling work we have continued our technical work, as digital signal processing specialists, in areas of applications of remote sensing and in some fundamental, but german studies, funded in a significant part by the National Science Foundation.

Thus, our work in the past year, and principally since our May 1974 progress report, articulates in the following categories.

1. Updating of the analysis and understanding of the California Water Project as a system.
2. Analysis and study of watershed models amenable to remote sensing inputs.
3. Application of signal processing techniques to user oriented problems.
4. Basic studies on signal processing algorithms pertinent to remote sensing applications.

2.1a Overview of the California Water Project - An Update (1,2,3,4)

An overview of the California Water Project has been presented in the May 1974 report. Our continuing work since that date has been directed toward the further elucidation of some aspects of the Project and an assessment of the evolving perspective and concerns of personnel of the California Water Project.

Earlier this year the Department of Water Resources made available the November 1974 update of the California Water Plan. The California Water Plan is a comprehensive master plan to guide and coordinate the

use of California's water resources for all beneficial purposes to meet present and future needs in all parts of the state. The plan is not a specific blueprint for construction but is, rather, a flexible pattern which can provide information and guidance relating to the use of the state's water resources, its future water requirements, and sources of water supply for California. The following excerpts are indicative, from our standpoint, of some of the major changes in the California Water Plan.

"The extent to which available supplies will cover future requirements is considerably less certain in 1974 than it appeared to be in 1970 because of highly significant events and trends that have occurred during the last four years -- major factors being the establishment of additional water requirements for water quality improvement and salinity control; the movement toward siting of power plants at inland locations rather than on the coast, also leading to a substantial additional water requirement; and the worldwide leap in demand for agricultural products."

Concerning Growth

"Irrigated agriculture increased at an average rate of 60,000 acres per year from about 8.5 million acres in 1967 to about 8.8 million in 1972. Irrigated area may range between 9.2 and 10.2 million acres by 1990, an increase of 5 to 16 percent. In 2020, irrigated land may range from 9.4 million to 11.4 million acres, an increase from 7 to 29 percent. The Department of Water Resources' land classification surveys show 22 million acres of irrigable land in California."

Concerning Water Demands

"1. Urban water use is now about 5 million acre-feet annually, and future demands are expected to range from 6.2 to 7.1 million acre-feet in 1990, an increase of 22 to 41 percent.

2. Present agricultural water use is 32 million acre-feet of applied water annually, or about 85 percent of total water use in the State. Demands for agricultural water in 1990 are expected to range from 34 million to 38 million acre-feet, an increase of from 7 to 19 percent."

Concerning Present Water Supplies

"1. California's present water needs are being met by existing state, federal, and local projects, and in some areas, especially the San Joaquin Valley, by overdrafting ground water supplies. More water is available from the existing projects than is being used now, and this reserve can be used to satisfy increasing demands for a number of years.

2. Total overdraft of ground water basins has decreased in the past four years by about 500,000 acre-feet per year, due to new water brought into the western San Joaquin Valley by the State Water Project and the San Luis Division of the Central Valley Project, thus replacing to some extent previous ground water use.

3. Conjunctive use of ground water basins and surface supplies can achieve more effective use of existing surface water supplies and would help conserve water that would otherwise spill from surface reservoirs during periods of high water. Additional study and exploration of the State's ground water basins are needed to adequately assess the potential for conserving additional surface water resources through conjunctive operation."

Thus, the following changes in the functions of the California Water Projects are anticipated for the future:

1. Water conservation, which is not an operational constraint at this time, will become more important and will affect operations.

2. Water quality problems are looming to be of more importance in the immediate future and in the long run. Maintaining some standards of flow rate and quality in the Delta may represent a major constraint on the possible operation of reservoirs.

3. Energy supply and demand factors.

a. The Department of Water Resources needs huge amounts of power and has given consideration to nuclear power plants for power generation.

b. Hydroelectric power has become more important and valuable and may lead to changes in the operation of the dams.

A significant economic benefit has been achieved by the California Water Project in power generation during the Winter 1973-73, by reexamination of the compromise achieved during the winter months between the requirements of flood control operations and hydroelectric power generation. In the short run, this potential increase in generated hydroelectric power appears as the only economic benefit to be expected from a modification of reservoir operations in the Feather River Watershed.

In broader terms, the cost and generation of energy is looming as a factor of increasing importance in the operation of the California Water Project. To understand this evolving situation, the diagrams of Figures 2.1a and 2.2a are informative. In Figure 2.1a, the water deliveries in 1973 indicate that only a small fraction of the water entitlement of Southern California has been delivered. Since water which originates at

Water Deliveries in 1973

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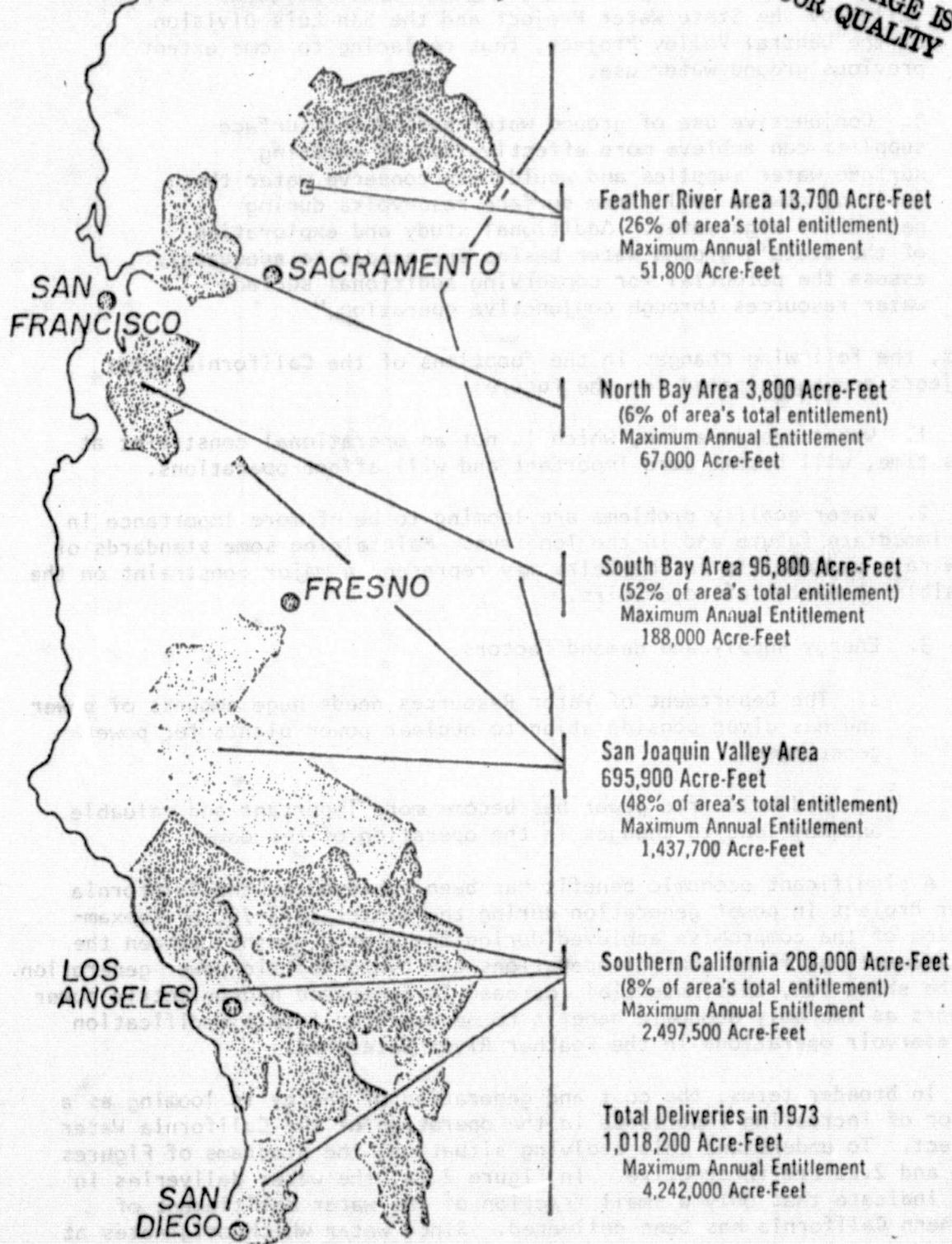


Figure 2.1a. Water Deliveries in 1973

Water Deliveries in 1973

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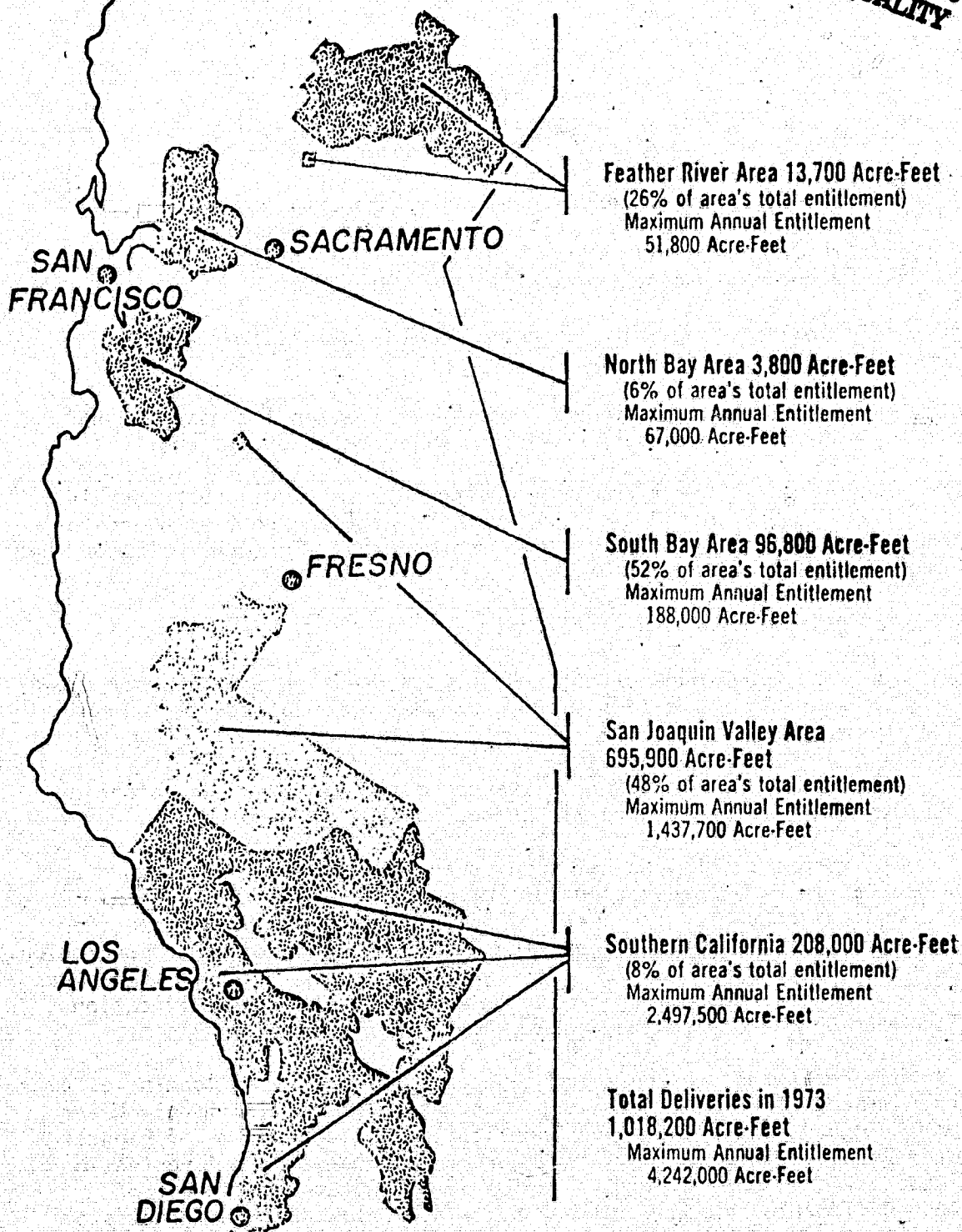


Figure 2.1a. Water Deliveries in 1973

an 800 foot elevation, at Lake Oroville, has to be pumped to more than a 3000 foot elevation over the Tehachapi Mountains, pumping energy required will increase rapidly as more water is delivered to Southern California. Figure 2.2a shows the evolving power consumption in the short run and in the long run.

As a result of the focusing of public attention on energy uses and energy resources, the California Department of Water Resources has carried out a background study on Hydroelectric Energy Potential in California, reported in the DWR Bulletin 194, March 1974. This study and discussion with personnel of the Department of Water Resources indicates a continuing reassessment of objectives and management of water resources in the State of California. We shall, in the coming year, keep informed of this evolving situation and report on changes with potential impact on remote sensing applicability.

2.2a Analysis and Study of Watershed Models Amenable to Remote Sensing Inputs

2.2.1a Introduction

We have undertaken in the past year a study of watershed models which are used operationally or which are given most serious consideration in technical literature.

Chronologically our work has proceeded as follows:

1. We started our work by a study of the technical literature and reports of work done on applications of remote sensing to hydrology. From this work, which is a continuing effort, it appears that the work most germane to our interest was that of Ambaruch and Simmons (5) on the use of remote sensing in the Kentucky Watershed Model.

2. The work of Ambaruch and Simmons suggested that a reasonable starting place in quantitative assessment of the potential of remote sensing inputs of a watershed model would be an evaluation of the sensitivity of the model to inputs and parameters. Although hydrologists have, from experience, a good feeling for the importance of various parameters, it appeared that a quantitative sensitivity analysis would be of more than academic interest.

3. We then proceeded to analyze the RFC hydrologic model to establish such a sensitivity to inputs and it became apparent that such work cannot be carried out analytically. The reason for this is that hydrologic models, such as the RFC model or other models based on the Stanford Watershed Model, are only partly analytical. Some of the parameters are actually determined by computer optimization during a calibration phase. This type of optimization, known in the engineering community as system identification, consists of the computer determination of unknown parameters of a model so that the output of the model approximates physical outputs in an optimum fashion, according to some objective function or approximation measure.

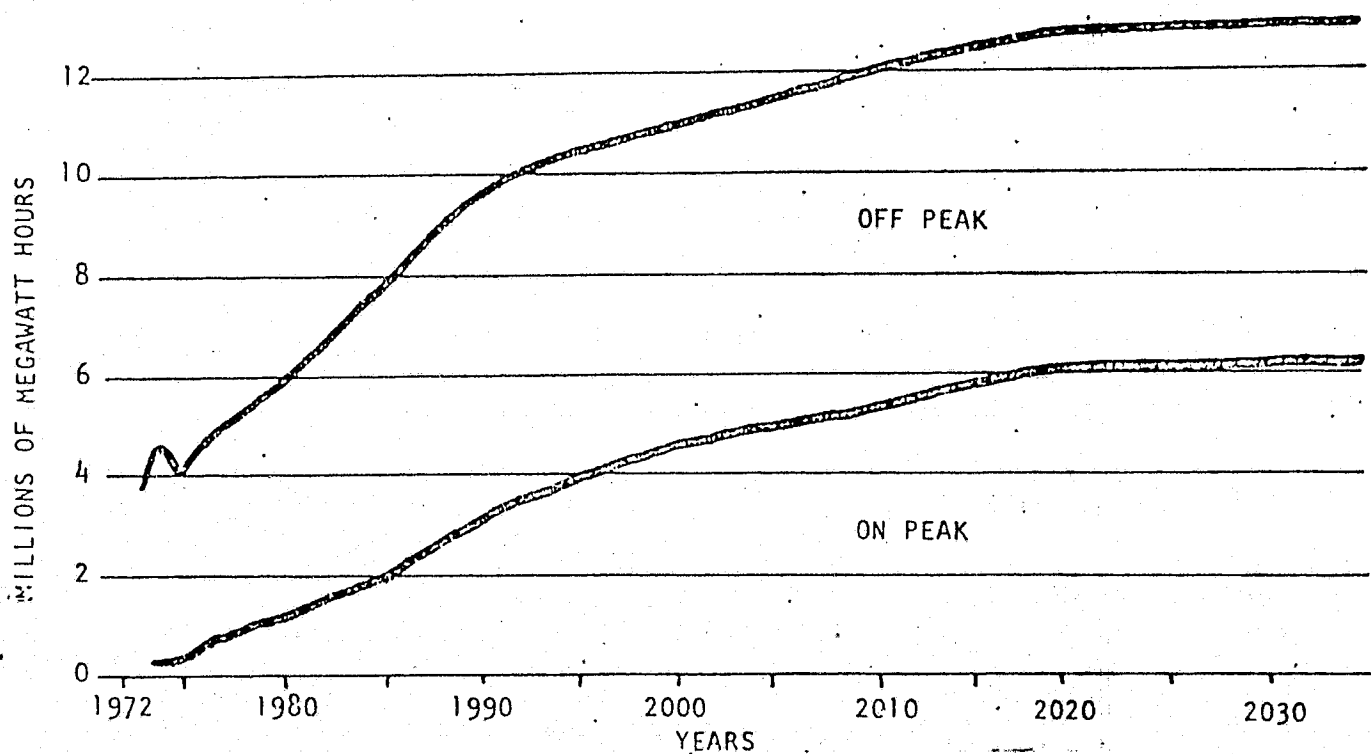
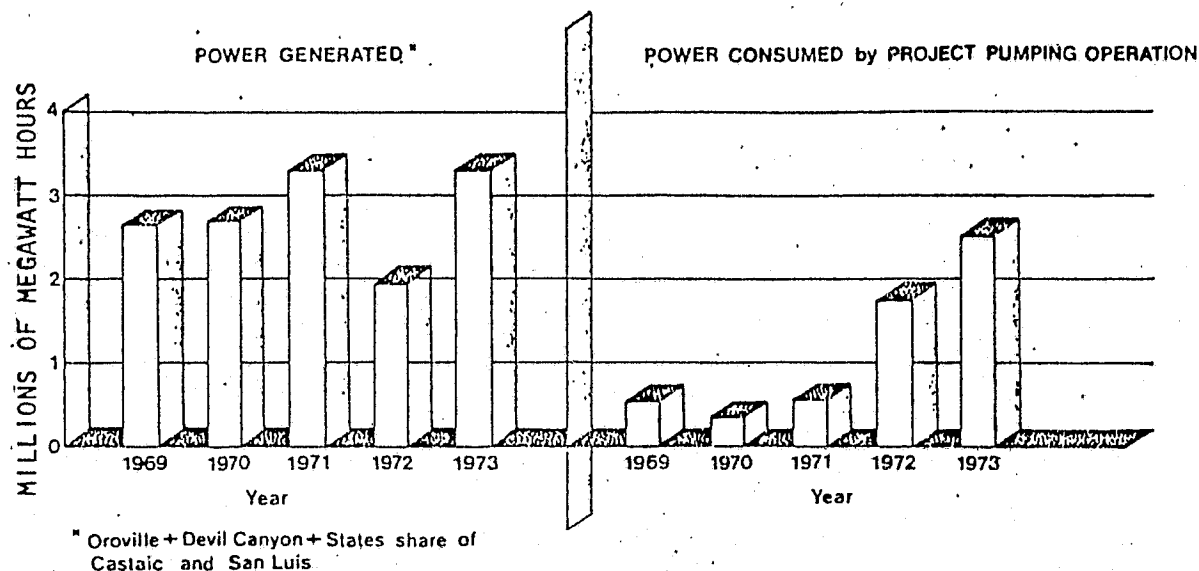


Figure 2.2a. Projected Power Generated and Pumping Energy Requirements Associated with the California Water Project.

4. Given this state of affairs, it became clear that the quantitative study of hydrologic models would require their actual implementation on one of our computers, the availability of the programs, input data sets, output data, germane historical records, etc.

5. By direct contact with J. Brown and C. Howard of the Department of Water Resources, Snow Surveys, we have obtained some preliminary information and documentation on the CCSS model, which we believe we can implement with a limited amount of time and effort.

6. Randy Thomas of the Remote Sensing Project in Berkeley has been in communication with the personnel of the Department of Water Resources responsible for the operation of the RFC Model, to clarify the procedures and conditions under which the RFC Model and operational data will be made available to personnel of the University of California. A formal agreement has been reached which allows us to proceed with this phase of our work.

7. In parallel with the above work, we have done some work (not supported by the grant) on the application of remote sensing to hydrology for the Hydrologic Engineering Center, Corps of Engineers (HEC) in Davis. This work, carried out in cooperation with R. Burgy, has made us familiar with some other hydrologic models used by hydrologists and civil engineers. It has also made us familiar with the work of Blanchard (6) on the use of remote sensing in the hydrologic model of the Soil Conservation Service, Department of Agriculture. Finally, we have become informed of several engineering applications of hydrologic modeling.

2.2.2a A Discussion of Hydrologic Models*

The study of hydrology has two main paths which relate to the basic motivations of the workers in the field. On the one hand we have research activities into the physical phenomena related directly or indirectly to the hydrologic cycle.

On the other hand, a great deal of work has been done on the investigation of hydrologic systems for the explicit purpose of establishing quantitative relationships between precipitation and runoff, which can be used for reconstruction or prediction of flood sequences and watershed yields. This is illustrated in Figure 2.3a, taken from reference 7.

*In some of this discussion we have borrowed and paraphrased freely from the paper by Amorocho and Hart (7).

PHYSICAL
HYDROLOGY

TYPICAL TOPICS OF STUDY

METEOROLOGY AND
CLIMATOLOGY
ENERGY CONVERSION
AND TRANSFER
BIOSYSTEMS
WATERSHED HYDRAULICS
AND HYDROMECHANICS

PARAMETRIC AND STOCHASTIC
HYDROLOGIES

PARAMETRIC METHODS

CORRELATION ANALYSIS
PARTIAL SYSTEM SYNTHESIS
WITH LINEAR ANALYSIS
GENERAL SYSTEM SYNTHESIS

GENERAL NON-LINEAR
ANALYSIS

STOCHASTIC METHODS

MARKOV CHAINS
MONTE CARLO METHODS

Figure 2.3a: Topics and methods of hydrologic study.

In fact, there has been a systematic increase in the use of "physical parameters" into parametric and stochastic hydrology, and we believe that the use of remote sensing data represents a further step in that direction.

Let us now consider certain pertinent definitions and concepts. According to a proposed ASCE (American Society of Civil Engineers) definition, " 'parametric hydrology' is the development of relationships among physical parameters involved in hydrologic events and the use of these relationships to generate, or synthesize, nonrecorded hydrologic sequences." Another definition states that " 'stochastic hydrology' is the use of statistical characteristics of hydrologic variables to solve hydrologic problems. This often involves the generation of nonhistoric sequences to which certain levels of probability can be attached."

Methods of system investigation share two characteristics: dependence on historical records of the values of the parameters and the assumption of stationarity or time invariance of the hydrologic systems. The first characteristic (historical dependence) means that, to the extent that historical records of the input and the output are affected by systematic and random errors of measurement, by inhomogeneity, and by lack of completeness, the results of parametric or stochastic hydrology are affected also. The second characteristic (time invariance) requires that hydrologic systems must not change with time, relative to their behavior during the recorded past.

The discussion and definitions above are important in clarifying two possible meanings for the terminology "operational hydrologic models." The first meaning refers to hydrologic models used in the operation of existing

water resource systems. The second meaning refers to models actually used for the study of watersheds and the design of dams and reservoirs. Examples of such models are the simulation models used by the Corps of Engineers and other State and Federal agencies such as the models HEC-1 or STORM (8). The manner in which these models are used falls more commonly within the realm of stochastic hydrology. More importantly, it seems apparent that the potential economic impact of remote sensing technology is vastly greater as it affects the design process of water resources systems and facilities, than in the management of existing systems (9). For an excellent discussion of the historical steps in the development of hydrologic models and their application see Dawdy (10).

2.2.2.1a Lumped-System Models and Distributed-System Models

Simulation of natural hydrologic systems may be achieved by means of either a lumped-system model or a distributed-system model. When the system is simulated by a lumped-system model, it is treated as a "black box." A gross representation of the black box is determined from the input and output data pertaining to the box, but no interest or concern is given to the processing going on inside the box. In such models, the use of space coordinates or position is not important and all parts of the system being simulated are regarded as being located at a single point in space. On the other hand, if the internal process of the model is analyzed, the system is not regarded as being considered at a single point in space but various distributed points or areas within the internal space of the system must be simulated, thus constituting a distributed-system model. The use of a lumped-system model does not explain the basic mechanics of flow through the watershed because it is only a simulation of the black box as a whole and offers in effect only a mechanical aid to data fitting.

By distributed-system models, the simulation of rainfall and runoff relationships as exemplified above has resort to hydrodynamic laws and principles. The distributed-system model involves more than one independent variable, that is the space coordinates, in addition to the usual time variable (11).

The current situation as regards operational hydrologic models is a mixed one, in which a lumped model is used with physically based (or physically plausible) components which model average properties of the watershed. There is obviously a nonphysical aspect to such models, The justification for their use is on empirical grounds.

2.2.2.2a Current Hydrologic Models

As discussed earlier, current hydrologic models are increasingly using "physical parameters." This transition has occurred quite recently and is by no means universal. Quoting a recent (1974) survey article by Monro and Anderson (12) research hydrologists with the National Weather Service:

" Most forecast procedures currently used operationally in the field are based on index methods such as the Antecedent Precipitation Index (API) rainfall-runoff relationship. A few of the River Forecast Centers have developed or adapted conceptual models for local use, but no specific model has been adopted for general use. The term "conceptual model" refers to a synthetic model of the rainfall-runoff process. A synthetic model contains elements defined by explicit functions which are assumed to represent all significant physical components of the rainfall-runoff process. The parameters used in the functions are determined through the use of input/output data.

Work (at NWS) on conceptual simulation models and studies of the physical processes of the hydrologic cycle has been in progress for several years. In 1971, the laboratory decided to publish descriptions of the necessary steps for developing operational river forecast procedures for continuous hydrologic forecasts, based on a conceptual hydrologic model, and digital computer programs needed for implementation.

Purpose

Comparison studies by the Hydrologic Research Laboratory show that some of the recent conceptual models have an accuracy advantage over the API technique. In addition, future hydrologic forecasts will extend beyond the forecasting of river stage and discharge to include such variables as water temperature, the amount of sediment transport, and the movement of pollutants. Conceptual models are much better suited for adaption to those future forecasting problems than are index methods, e.g., API. It was decided that conceptual models should replace API as the basic tool for hydrologic forecasting as quickly as time and manpower permit."*

Note in that regard that the Sacramento RFC model is not yet applied operationally to the Feather River Watershed.

Basic objectives for efficient use of conceptual river forecasting models on a nationwide scale are as follows:

- "1. An efficient means of retrieving and processing basic data for model parameter calibration must be provided.
2. The soil-moisture accounting and channel-routing procedures must be applicable over the wide variety of hydrologic and climatic conditions found in the United States.

*Underlining is mine (VRA).

3. An efficient calibration procedure which would permit calibration of a large number of basins in a reasonable time is a necessity."

2.2.2.2.1a API Models and Rational Formulas (13,14)

These traditional models are still widely used in many applications and for design purposes. These are generally single storm models.

SCS (Soil Conservation Service) Model

The model was developed mainly for small watersheds for which only daily rainfall and watershed data are ordinarily available. The SCS runoff equation is a method of estimating direct runoff from storm rainfall of one day or less.

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S}$$

Q = accumulated direct runoff

P = accumulated rainfall (potential max. runoff)

Ia = initial abstraction including surface storage, interception, and infiltration prior to runoff

S = potential max. retention

The following relationship between Ia and S was developed from experimental watershed data: $Ia = 0.2S$; if we transform S to a new parameter, C, then

$C = \frac{1000}{10 + S}$. So the problem is reduced to one of estimating a single parameter,

C, which can be derived from the soil type, slope, and visible ground cover of the watershed. This is the model on which the work of Blanchard using ERTS-1 data (6) and microwave remote sensing (15) is based.

Other single storm API models are commonly in use. In a representative model by Sittner, Schauss and Monro (14), the quantity of runoff from a given storm is determined by the moisture deficiency of the basin at the beginning of the rainfall and by such storm characteristics as rainfall amount, intensity and duration. In this model, the API is used as an index to moisture conditions within the basin at the beginning of rainfall.

$$P_a = b_1 P_1 + b_2 P_2 + b_3 P_3 + \dots + b_t P_t$$

where b_t is a constant and P_t is the amount of precipitation which occurred t days prior to the storm under consideration. The constant b_t is commonly assumed to be a function of t, such as $b_t = 1/t$. If a day-by-day value index is required, as in the case of river forecasting, there is considerable advantage in assuming that b_t decreases with t according to a logarithmic recession rather than as a reciprocal, i.e., $P_{at} = P_{ao} k^t$, where $b_t = k^t$.

The value of the recession factor k is a function of the season and varies from one region to another. If sufficient data are available, variations of k can be determined through statistical analysis. The snowfall in this model can be considered to have been applied to the basin on the day it melted rather than when it fell.

Similar models of the API type are used for snowmelt. In particular, the primary CCSS model described in a previous progress report made use of 4 indices to forecast the April to June runoff.

2.2.2.2.2a Conceptual Parametric Models

A discussion of the Sacramento RFC model, which is one such conceptual model, has been given in a previous report. Therefore, at this point we will merely highlight some of the important properties and requirements of such models.

Data requirements for the conceptual model differ from those for the API-type technique in two ways: (1) Data for parameter calibration purposes must be continuous; and (2) some form of potential evapotranspiration (PE) data may be required for both calibration and operational forecasting. Precipitation data (six hourly areal mean precipitation values are used) and streamflow data are needed. For calibration, mean daily discharge is required. Although the model simulates streamflow for a shorter time interval (currently 6 hours), model parameters are determined by comparing computed and observed mean daily discharge. Instantaneous hydrographs for selected events also may be necessary to determine channel routing parameters. Operationally, no observed streamflow data are required, but the quality of the final product is improved if observed data are used periodically to update the model.

Thus, the way in which these newer conceptual models differ from older API type models is in soil moisture accounting. It is because of this capability that Monro and Anderson (12) state:

"...these models show a very significant accuracy advantage over API only under one condition. This is in the modeling of river response after a long dry period. However, since long dry periods occur everywhere to some degree, the improved accuracy during these situations can be very important."

These models require a substantial period of records of inputs and outputs for calibration purposes. A 10 year calibration period is suggested by Monro and Anderson as adequate for most basins.

Thus, the potential use of remote sensing in hydrologic models follows two possible lines.

1. The estimation of soil moisture parameters of existing lumped conceptual models.

2. The use of the spatial information available through remote sensing to obtain, for the first time, techniques which will meaningfully handle distributed conceptual models.

In the following, we shall describe our current work which is germane to these two different approaches in the application of remote sensing techniques to hydrology.

2.2.2.2.3a Implementation of the Sacramento RFC Hydrologic Model

After the formal agreement between personnel of the University of California NASA Grant and Mr. Burnash of the NWS, Sacramento on the use of the RFC model, we have undertaken to implement this model on the campus computer at Davis.

The purpose of this work is twofold.

1. To study the sensitivity of the model to its primary parameters for the specific conditions which exist in the Sierra Nevada.

2. To simulate the effect on the operation of the model of those parameters which are estimated by remote sensing.

The interest of sensitivity analysis in hydrologic modeling is well documented (16) and is of use in all phases of the modeling process: model formation, model calibrations and model verification. Our objective is to rank variables and parameters in an order of relative importance, which accounts for the intended hydrologic characteristics of the model.

The RFC model consists of a soil moisture model and a snow submodel. At this time, the main program of the soil moisture model for the Middle Fork of the Feather River has been implemented on the campus computer. We are in the process of acquiring and reformatting the 10 years of historical records which are used in the calibration phase of the model.

The graphs of Figures 2.4a and 2.5a illustrate use of the model parameters and the type of results obtained in simulation. They also allow a discussion of the problems that we consider of major interest.

Figures 2.4a and 2.5a show the actual runoff, and the runoff predicted by the model, for the months of January 1969 and May 1969, in cubic feet per square mile. The actual runoff is indicated by * and the predicted runoff by +. The meaning of the symbols used is given in Table 2.1a. The procedure used to calibrate the model is described in the Sacramento RFC Model, User Manual of Burnash and Ferral. The two examples shown illustrate that different conditions and requirements pertain to different times of the water year. The condition of the watershed as indicated by the contents of Upper Zone and Lower Zone tension and free water are significantly different for the months shown. The month of January experienced a storm (note the nonlinear scale for the runoff graph) for which the short time behavior of the model,

such as peak runoff, is of major interest. In May the accuracy of a volumetric forecast may be of more significance.

These questions will be explored further in the coming months by our considering both the sensitivity of the runoff to variations of model parameters at various periods in the water year and also the accuracy required of these parameters. The use of average values of these parameters acquired by remote sensing for the entire watershed will be then considered. We expect in that phase of the work to cooperate with the Berkeley group headed by Randy Thomas and examine the usefulness of the detailed information on evapotranspiration potential, currently gathered by that group.

2.2.2.2.4a Snow Areal Mapping and Snow Modeling

A substantial number of studies on the areal mapping of snow using remote sensing have been undertaken in the past few years (17, 18, 19) and have evolved into a handbook of techniques for satellite snow mapping (20) sponsored by NASA. These techniques are being used quasi operationally in several regions of the United States and in particular by the California Cooperative Snow Survey Program of the Department of Water Resources.

We note that most of the physical basis for snow ablation has been understood and modeled for a number of years (21). The recent work of Armbaruch and Simmons (22) on the sensitivity of the Stanford Watershed Model gives the results of Table 2.2a for the sensitivity and permissible tolerances of the snow submodel. In that table the sensitivity is indicated roughly by the ratio of the permissible tolerance to the simulated runoff.

On the basis of all the information available, the following physical qualities appear to be of prime interest in the modeling of basinwide snowmelt: the temperature, the albedo, the topography and areal extent of the snow, the spatial distribution of precipitation, and the snowcover. Further, it is well known that these parameters vary substantially across the snow-covered area and change fairly rapidly with time. On that basis we have undertaken a study to incorporate satellite data into a physically based, distributed model of snowmelt in runoff prediction. We have obtained some partial technical results.

(a) Measurement of Temperature Fields Using NOAA Data

We have obtained digital data from the NESS-NOAA Satellite field station in Redwood City gathered by the NOAA-3 and NOAA-4 satellites, both in the visible and in the thermal infrared bands. We have examined whether the data would allow a quantitative measure of the temperature field across the snowpack. Since the NOAA-3 and 4 data are effectively uncalibrated, we had to first establish that the data provided sufficient discrimination of temperatures to make a measurement possible. We show in Figures 2.6a and 2.7a a LANDSAT color composite and a ~~pseudo-color display~~ of thermal NOAA-3 data on the snowpack for a part of the Sierra Nevada which included the Kings

Table 2.1a Definition of symbols used in the RFC Hydrologic Model

1. Upperzone tension water
 - a) UZTWM, maximum capacity in inches
 - b) UZTWC, contents in inches
2. Upper zone free water
 - a) UZFWM, maximum capacity in inches
 - b) UZFWC, contents in inches
 - c) UZK, lateral drainage rate
3. The percolation rate from upper zone free water into the lower zone
 - a) PBASE, the through-put rate during saturated conditions
 - b) Z, the proportional increase in percolation from saturated to dry conditions
 - c) REXP, an exponent determining the rate of change of the percolation rate with changing lower zone water contents
4. Lower zone tension water
 - a) LZTWM, maximum capacity in inches
 - b) LZTWC, contents in inches
5. Lower zone free water
 - a) Supplemental free water storage
 - 1) LZFSM, maximum capacity in inches
 - 2) LZFSC, contents in inches
 - 3) LZSK, lateral draining rate
 - b) Primary free water storage
 - 1) LZFPM, maximum capacity in inches
 - 2) LZFPC, contents in inches
 - 3) LZPK, lateral drainage rate
 - c) PFREE, direct percolation to Lower Zone Free Water
 - d) Ground water discharge not observable in the river channel
 - 1) SIDE, ratio of non-channel subsurface outflow to channel baseflow
 - 2) SSOUT, discharge required by channel underflow
 - e) RSERV, fraction of lower zone free water incapable of resupplying lower zone tension

Table 2.2a: Sensitivity and Tolerance of a Snowmelt Submodel.
From Ambaruch and Simmons [22].

INPUT OR PARAMETER	PERMISSIBLE TOLERANCES %	EFFECT ON SIMULATED RUNOFF, %	RELATIONSHIP TO WATERSHED GEO- MORPHOLOGY
PRECIPITATION (PERTURBED ONLY DURING STORMS)	+11 -11	+5 -5	ERRORS IN PRECIPITATION INPUT
EVAPORATION (PERTURBED ONLY DURING STORMS)	+20 -20	-5 +5	ERRORS IN EVAPORATION DATA
TEMPERATURE (PERTURBED ONLY DURING STORMS)	+2.3 -4.0	+20 -20	ERRORS IN TEMPERATURE DATA
FRACTION OF INCOMING RADI- ATION REFLECTED BY SNOW(FIRR)	+15 -12	-20 +20	SNOW SURFACE ALBEDO: INDE- PENDENT OF GEOMORPHOLOGY
SNOWPACK BASIC MAXIMUM FRACTION IN LIQUID WATER (SPBFLW)	+16 -13.5	-10 +10	SNOW PHYSICS: NO RELATION TO WATERSHED GEOMORPHOLOGY
SNOWPACK MINIMUM TOTAL WATER CONTENT (SPTWCC)	+0 -32.5	-1 +1	SNOW PHYSICS: NO RELATION TO WATERSHED GEOMORPHOLOGY
ELEVATION DIF- ERENCE BETWEEN BASE THERMOMETER AND MEAN BASIN ELEVATION (ELDIF)	+20 -12.5	-28 +28	BASIN TOPOGRAPHY
FRACTION OF SNOW INTER- CEPTED (FFSI)	+25 -25	+10 -10	TYPE AND DENSITY OF FOREST
PRECIP. INDEX FOR CHANGING SNOW ALBEDO (PXCSA)	+50 -11	+2.9 -10	SNOW PHYSICS: NO RELATION TO WATERSHED GEOMORPHOLOGY

UZTW UZFW LZTW LZFW S LZFWP UZ-K LZS-K LZP-K ZPERC REXP SIDE SSUUI PCITM SARVA RS
 CAPACITY 4.70 2.22 10.50 7.17 8.72 0.217 0.999 0.0080 21.5 4.80 0.16 0.0 0.020 0.006 0.3
 CONTENTS 4.67 0.0 8.42 0.10 0.94 ADIMP = 0.028 ADIMC = 12.415 PFREE = 0.200

		CFS/SQ.MI.												
Y	PCP	OBS	FCST	0	2	4	6	8	10	20	30			
1	0.02	0.59	0.40	I +*	I	I	I	I	I	I	I			
1	0.04	0.59	0.38	I +*	I	I	I	I	I	I	I			
1	0.05	0.58	0.38	I +*	I	I	I	I	I	I	I			
1	0.11	0.60	0.41	I +*	I	I	I	I	I	I	I			
1	0.07	0.64	0.36	I +*	I	I	I	I	I	I	I			
1	0.06	0.65	0.38	I +*	I	I	I	I	I	I	I			
1	0.08	0.66	0.38	I +*	I	I	I	I	I	I	I			
1	0.01	0.67	0.33	I +*	I	I	I	I	I	I	I			
1	0.01	0.63	0.32	I +*	I	I	I	I	I	I	I			
1	0.01	0.59	0.30	I + *	I	I	I	I	I	I	I			
1	0.15	0.72	0.38	I + *	I	I	I	I	I	I	I			
1	0.59	1.09	2.00	I *	I +	I	I	I	I	I	I			
1	1.49	4.66	5.08	I	I	I *	I +	I	I	I	I			
1	0.25	4.78	4.06	I	I	I +	I *	I	I	I	I			
1	0.02	3.10	2.14	I	I +	I *	I	I	I	I	I			
1	0.01	2.71	1.03	I	I +	I *	I	I	I	I	I			
1	0.01	2.06	0.64	I +	I *	I	I	I	I	I	I			
1	0.03	1.73	0.55	I +	I *	I	I	I	I	I	I			
1	0.98	6.79	3.43	I	I	I +	I	I *	I	I	I			
1	1.45	17.63	7.16	I	I	I	I	I +	I	I *	I			
1	1.76	24.77	11.47	I	I	I	I	I	I +	I *	I			
1	0.24	14.66	10.15	I	I	I	I	I	I +	I *	I			
1	0.04	9.23	7.15	I	I	I	I	I +	I	I *	I			
1	0.04	6.54	4.93	I	I	I	I +	I *	I	I	I			
1	0.44	7.57	5.27	I	I	I	I +	I *	I	I	I			
1	0.67	14.11	6.64	I	I	I	I +	I *	I	I *	I			
1	0.03	8.47	5.39	I	I	I	I +	I *	I	I	I			
1	0.05	7.16	4.31	I	I	I +	I	I *	I	I	I			
1	0.03	5.44	3.38	I	I	I +	I *	I	I	I	I			
1	0.08	4.46	2.96	I	I	I +	I *	I	I	I	I			
1	0.0	3.70	2.70	I	I +	I *	I	I	I	I	I			

MONTHLY TOTALS IN INCHES

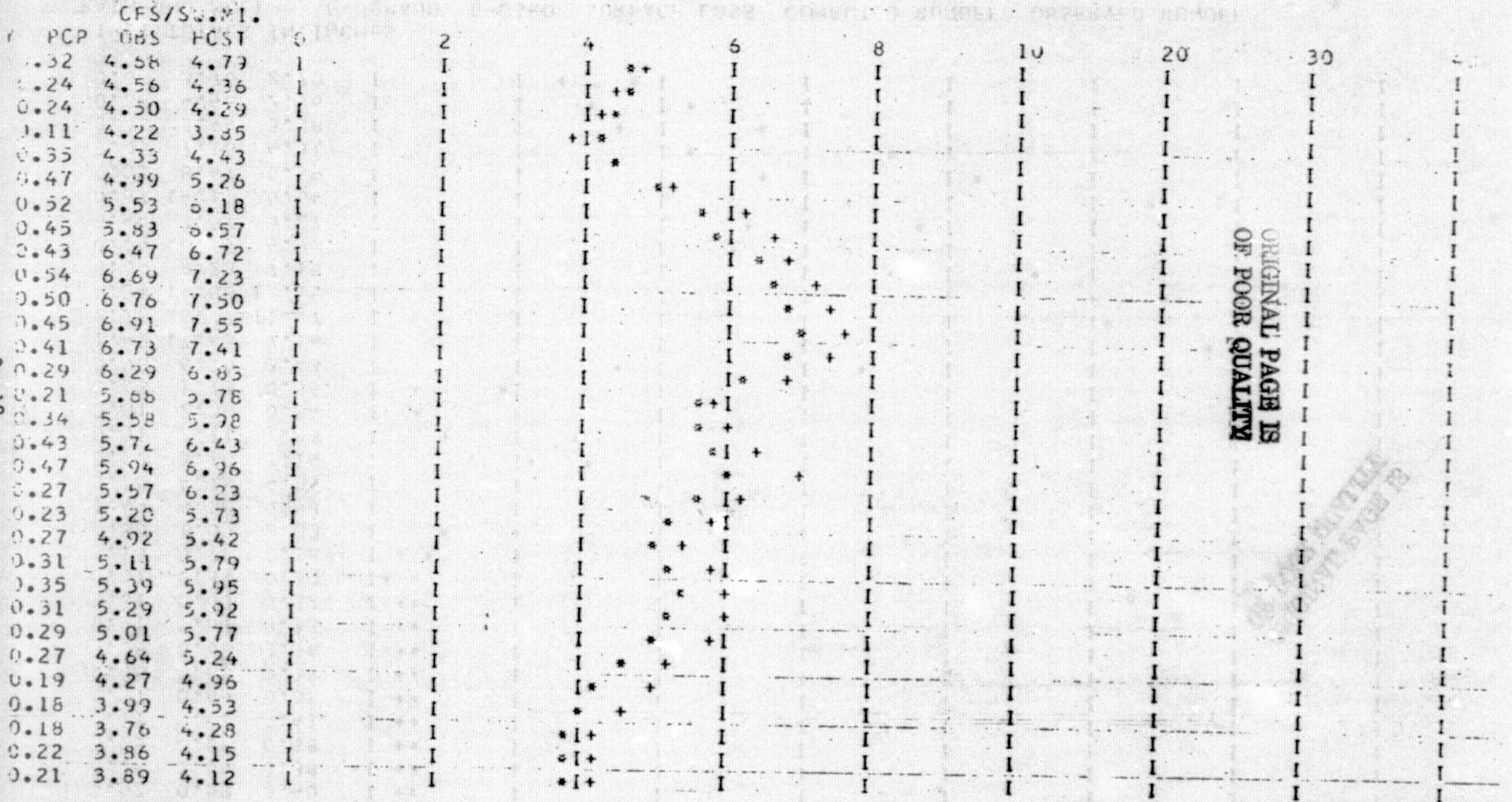
RAIN AND MELT 8.82 E-DEMAND 0.52 E-USED 0.52 SURFACE LOSS 0.00 COMPUTED RUNOFF 3.51 OBSERVED RUNOFF 5.86

MONTHLY WATER BALANCE ERROR = -2.35 INCHES

Figure 2.4a Runoff simulation for the month of January 1969.

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UZIW UZFW LZIW LZFW LZFWP UZ-K LZS-K LZF-K ZPERC REXP SIDE SSUUI PCTIM SARVA RSEV I
 CAPACITY 4.70 2.22 10.50 7.17 8.72 0.217 0.099 0.0080 21.5 4.50 0.16 0.0 0.020 0.003 0.34 0.
 CONTENTS 4.70 0.25 10.50 0.85 4.30 ADIMP = 0.026 ADIMC = 15.138 PFREE = 0.20



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Monthly totals in inches

Figure 2.5a Runoff Simulation for the month of May 1969

River Watershed. Similar regions on the two photographs can be identified. Careful examination indicates that more than 6 temperature steps can be identified across the snow. Isothermal lines can be determined readily.

(b) Comparative Estimates of Snow Areal Extent Using LANDSAT 1 and NOAA Data

We have undertaken a study of the possible use of NOAA data in the visible spectrum to estimate areal extent of snow. To proceed in a systematic manner we have done some work using LANDSAT 1 multispectral data and LANDSAT 1, band 5 (which is the visible band of NOAA-3) to see, under ideal conditions of scale and registration, whether the information can be extracted from the visible band alone. These results are fairly encouraging but not conclusive. We have developed a geometric correction program that we shall need to employ in proceeding to the next step, which entails using the NOAA data. A fairly good registration of NOAA data with maps or with LANDSAT-1 data is needed to make a quantitative comparison using the two satellites.

(c) Albedo Estimates

Although albedo is not measured by any of the satellites currently operational, we have undertaken a correlation study of snow brightness, as measured in band 5 of LANDSAT-1 with global brightness, estimated using all four MSS bands. The intent of the work is to determine whether snow brightness, as measured in particular by NOAA satellites in the visible band, gives an adequate indication of albedo for use in a snow model. Further work will also include ground truth or albedo acquired by Dr. Amorochio at the Central Sierra Snow Laboratory.

The scope of this work will enlarge considerably in the near future since we are planning to build up a file on available NOAA data covering the Sierra Nevada for at least part of the snowmelt season from April to June, 1975. We shall also acquire available and pertinent LANDSAT data.

We anticipate that the continuation of this work will be done in cooperation with Dr. Jaime Amorochio, a well known hydrologist with many years of experience in hydrologic modeling.

Dr. Amorochio's statement of his views on the incorporation of remote sensing inputs and data on his current and previous work on snow modeling follows.

2.2.2.2.5a Hydrologic Modeling of Snowpack Evolution with Satellite Data (Dr. J. Amorochio)

A decade ago, Amorochio and Espildora (1966) developed a mathematical model for simulation of the snow melting processes, which was based on data obtained at the Central Sierra Snow Laboratory of the U.S. Forest

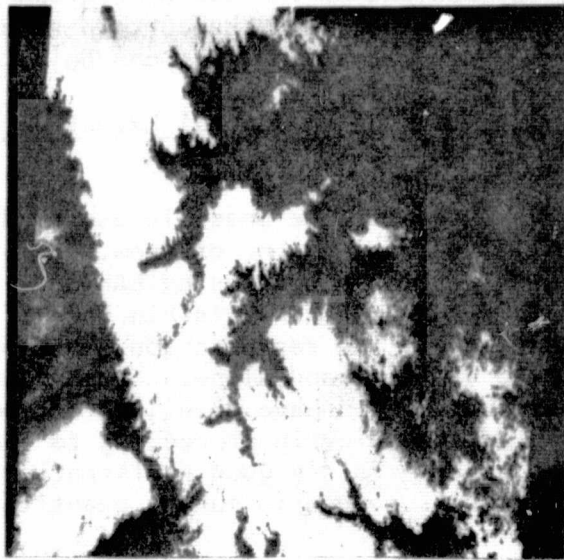


Figure 2.6a: LANDSAT-1 Composite--Snow Covered Sierra Nevada

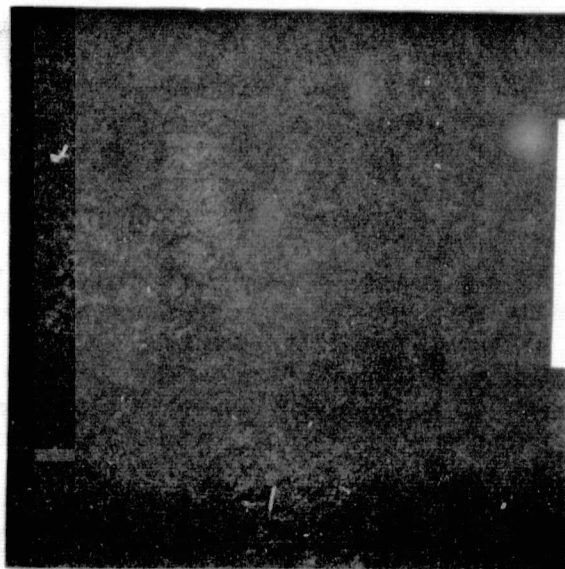


Figure 2.7a: NOAA Thermal IR Pseudocolor Display of the Same Area as Figure 2.6a

Service. This model was later retested with data from a special snow lysimeter designed and installed in the Andes Mountains in Chile, by Amorocho and Espildora under the University of California - University of Chile cooperative program (1967-1971). In this installation, the actual snow melt rates were measured simultaneously with all of the climatological variables required as input data to the model. The results were encouraging (Stowhas, 1968; Espildora and Stowhas, 1971) and led to some refinements in the model structure which resulted in improved computational efficiency.

In 1973, a new, highly instrumented snow lysimeter facility was designed and constructed at the Central Sierra Snow Laboratory in California. This facility was designed by Amorocho while leading a group at the University of California, Davis, in collaboration with the U.S. Bureau of Reclamation and the U.S. Forest Service. Detailed data on snowpack variables, including net melt rates, are being presently collected, and used in further testing of the mathematical models for California conditions.

The above experiences furnished valuable information on the physics of the snow melting processes and their simulation. It was evident, however, that the input data furnished by highly instrumented installations such as those used by the investigators, would not be available in general on a regional basis. Accordingly, a new study was undertaken by Stowhas under the direction of Amorocho, which culminated in the development of a new simulation model (Stowhas, 1975) which can operate under more severe data constraints. This utilizes relationships developed experimentally at the Chile station, and permits the computation of snowmelt rates throughout the year from a modest data base.

The variables required for the operation of the new model are as follows:

1. Net exposure to solar radiation (sun hours and cloud cover)
2. Wind speed
3. Air temperatures near the snow surface
4. Relative humidity
5. Precipitation

Measurement of these variables can be accomplished at ground stations without the requirement of very complex instrumentation. However, it is also recognized that whereas the model was tested successfully with data obtained, at a point, meteorological variables listed above may have large spatial and temporal variations within a region. It is believed that, with the aid of satellite data, most of these variables can be evaluated in time and space. The following program is suggested to verify this possibility and to develop an operational procedure to permit continuous computation of snowmelt on a regional basis:

1. Development of procedures for the preparation of digital display maps or two-dimensional matrix arrays of processed satellite data serving as variable values or index values leading to the space and time evaluation of:
 - a) Local cloud cover and sunshine coefficients,
 - b) Local albedo of the snowpack when perceivable from the satellite
 - c) Local ground level temperatures
 - d) Wind fields
 - e) Snow line contours
 - f) Precipitation estimates or precipitation indices (may be combined with weather radar data)
2. Development of a mathematical model, based on existing models, capable of accepting the above satellite data as inputs, in conjunction with a minimum of ground data, for the computation of snowpack evolution.
3. Test of model per (2) above by means of detailed ground truth measurements at the Central Sierra (California) and Chile laboratories, and evaluation of:
 - a) Accuracy of satellite estimates of the variables at the locations of the stations
 - b) Accuracy of snowmelt predictions based on satellite data
 - c) Possible improvements in procedures and in future satellite remote sensing needs
4. Development of operational procedures for routine conjunctive utilization of satellite and ground data in snowmelt prediction.

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2.3a Application of Digital Processing Techniques in Remote Sensing

2.3.1a Delineation and Mapping of Snow Cover and Estimation of Areal Extent

As we mentioned earlier, we are continuing work on enhancement pre-processing and quantification of snow cover. The technique which combines multispectral enhancement, ratioing to reduce the effect of shadows in mountainous areas, masking part of the image, and likelihood-ratio classification seems to provide good estimates of snow extent from multi-spectral data. To quantify this assessment and compare the results of other workers, we need to delineate the watershed on the data and thus to do some geometric correction of the data. These last two steps have just now been implemented. We are also studying estimates of snow extent from a single spectral band, as we discussed before.

2.3.2a Mapping and Enhancement of Salt Affected Soils

This work carried out by A. Samulon, a Ph.D. student, has been completed technically and is described by Samulon as follows:

"This work includes the design and implementation of a nonstationary linear digital filter which extracts the natural features from high altitude imagery of agricultural areas. Essentially, from an original image a new image is created which displays information related to soil properties, drainage patterns, crop diseases and other natural phenomena, and contains no information about crop type.

A model is developed to express the recorded brightness in a narrow band image in terms of crop type and crop vigor and which describes statistically the spatial properties of each. Based on this model, the form of the minimum mean square error linear filter for estimation of the natural component of the scene is derived and a sub-optimal filter is implemented. Non-stationarity of the two dimensional random processes contained in the model requires a unique technique for deriving the optimum filter.

Finally, the filter depends on knowledge of field boundaries. An algorithm for boundary location is proposed, discussed and implemented."

We have now undertaken the application of these algorithms to the specific problem of mapping salt affected soils. This is an important problem related to irrigation, which has been drawing the attention of the DWR and county agricultural officials in California. Since ground truth is available in parts of California, we shall assess this technique by comparing it to available maps and determine to which class of problems the method applies. A research assistant will specifically consider this area of application.

2.4a Digital Image Processing Techniques Development

Our efforts in the specific technical field of digital processing have followed two parallel goals: to pursue vigorously the specific areas of work in which we feel we can make a valuable contribution and to incorporate into our facility and software the algorithms and techniques developed by others which seem to have most merit in applications.

2.4.1a Spectral-Spatial Combination of Multispectral Data

Because of the high correlation both spectrally and spatially in the LANDSAT-1 data, it seems possible to achieve at the same time, several of the following objectives.

1. Improvements of the quality of the data by reduction of the noise due to errors and coarse quantization.
2. Efficient representation of the data either for transmission (encoding) or for further processing. It appears probable that this capability can be achieved without any loss in, and possibly with a net improvement of, data quality.
3. Presentation of the information provided by sensors in a more interpretable form. This is related to our work in image enhancement.
4. Significant increase in the speed of processing for enhancement or classification. This capability depends upon the choice of linear combination with fast algorithms.

Significant results have been achieved on points 1 and 2 above. A set of filtering algorithms has been developed and is being tested in applications. Under sponsorship of the National Science Foundation, a new approach to image encoding, applicable to multispectral data, has been developed. Preliminary results have been presented at the 1974 Picture Coding Symposium, Goslar, West Germany and some of these results are summarized in the appendix. In the coming months we are planning to ready work on 2 and 3 above for publication. Results obtained by B. J. Fino and V. R. Algazi on 4 have been submitted for publication and some additional work, under the sponsorship of NSF, has been proposed.

2.4.2a Geometric Correction

We have implemented some simple geometric correction algorithms. We are planning to assess the range of applications for which this level of correction is adequate. We are also working on some subpixel processing algorithms which bear on the problem of radiometric degradation resulting from sophisticated geometric correction of the data.

2.4.3a Subpixel Processing

In some applications, notably the quantitative determination of water surfaces, it is desirable to incorporate subpixel information. For advanced geometric correction, it is also desirable to interpolate between pixels. A systematic approach to the design of efficient filters and algorithms for that problem has been undertaken by a Ph.D. student, Minsoo Suk, with partial support of the grant. A paper on basic design considerations has been submitted for publication to the IEEE Society on Circuits and Systems. Both fundamental and applied work in this area will be continued. In particular, the work by May (23) presented at the 3rd ERTS Symposium, will be examined in the light of the fundamental limitations discussed in our work.

This work takes special significance in the applications (mentioned in Section III-D) which use low resolution data such as the NOAA satellites.

2.4.4a Noise Removal

In our work with NOAA-3 and NOAA-4 data we have encountered difficulties with the quality of the data. NOAA is quite concerned with this problem which limits the usefulness of the data, principally in the thermal infrared. Using our previous experience on noise stripping in the LANDSAT 1 satellite, we have been able to reduce this noise by digital processing. Further work may be done on this problem under the sponsorship of NOAA, which will lead to the development of a computer program which would be used by satellite field stations.

2.5a Publications and Technical Presentations

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- (2) V. R. Algazi, "Some Remote Sensing Applications of Digital Signal Processing", Proc. of the 1974 Asilomar Conference on Circuits and Systems, pp. 285-284 (reprint attached).
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- (5) V. R. Algazi, "Input Quantity Encoding of Multispectral Data", presented at the 1974 Picture Coding Symposium, Goslar, West Germany, August 1974 (summary attached).
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Appendix I

Input Quality Encoding of Multispectral Data*

V. Ralph Algazi

Presented at the 1974 Picture Coding Symposium, August 1974, Goslar, West Germany.

1. INTRODUCTION AND OBJECTIVES

In the efficient representation and encoding of data, the engineer will generally exploit the statistical redundancy that is present in the data and try to accommodate the fidelity requirements specified by the user. In the case of multispectral data, in which many users are involved, it is difficult to specify a data quality which will accommodate all users. For error-free analog data it is well known that an infinite bit rate is needed to represent the data exactly. Assuming digitized data, Spencer and May (1) have examined error-free encoding techniques which use differential encoders. However, a more general statement as to the quality acceptable in the encoding of multispectral data is that encoding should preserve data quality as determined by image sensors and input quantization. Thus we can use data correlation for quantization noise reduction as well as for encoding with some errors, as long as the total error in the digital data is not larger than the total error in the original data. We have used linear transformation techniques and some theoretical results of others and ours to study this problem (2,3,4).

2. THEORETICAL BASIS

The steps in the optimum encoding of noisy source are shown below:



In the mean-square sense the optimum filter is followed by the optimum encoder

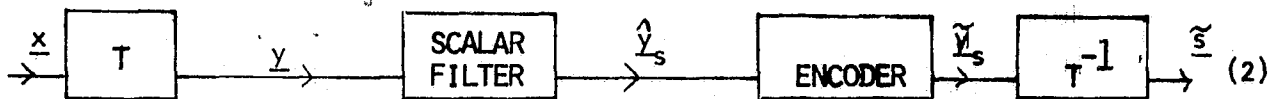
D_{est} = Residual estimation M.S. error

D_{cod} = Encoding M.S. error

then the encoding preserves the input quality of the data.

*Work supported in part by NSF Grant GK-37282

In filtering and encoding use Karhunen-Loeve transformation for optimum results for finite block size. Recursive techniques can be used in encoding and/or filtering in suboptimum schemes. When using transforms we schematically have the following



in which T is the Karhunen-Loeve or a fast unitary linear transformation.

3. THEORETICAL RESULTS BASED ON ACTUAL DATA

In the theoretical analysis of this approach to encoding we have assumed the following models:

a. Quantization Error: $\sigma_n^2 = \frac{Q^2}{12}$, σ_n^2 quantization error variance we

assume L quantization levels, $Q = \frac{6\sigma_s}{L} = \frac{6\sigma_s}{2^b}$, in which there are b bits quantizer between $\pm 3\sigma_s$.

b. Image Statistics: Gaussian, zero mean

Spatial: Separable first order Markov

$$[s_{ij}s_{kl}] = e^{-\alpha[|i-k| + |j-l|]}$$

$$.05 \leq \alpha \leq .15$$

which fit LANDSAT-1 data quite well.

Spectral: We use LANDSAT-1 multispectral scanner statistics. We verified that spectral-spatial statistics are separable.

We have examined the results achievable using most of the transforms of interest: Karhunen-Loeve (KL), Discrete cosine (DC), Fourier (FR), Hadamard (HD), Harr (HA), slant Hadamard (SLD), Slant Harr (5) (SLHA), and the effects of encoding one dimension, two dimension spatially, on a spectral-spatial encoder.

We illustrate the results obtained by two graphs. In Figure 1, we show the number of bits needed to represent the data, assuming the number of quantization levels shown in abscissa. The encoder uses a 4 x 4 x 4 block of data. We note that most fast transforms perform as well as the optimum Karhunen-Loeve.

In Figure 2, we illustrate the effect of data statistics, in particular, of the spatial correlation of the data. We note that a theoretical rate of 2 bits per cell is possible with data degradation, starting from 6 bit quantized data.

4. EXAMPLE OF IMPLEMENTATION

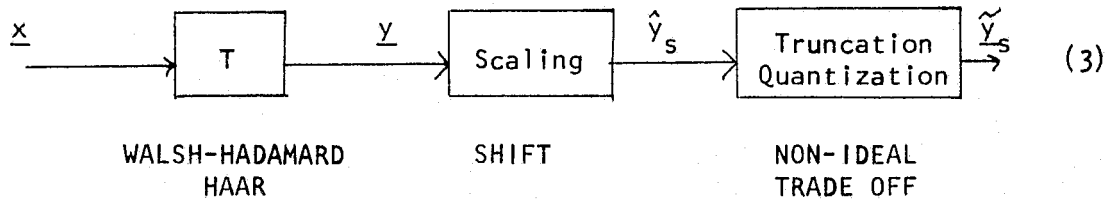
We used LANDSAT-1 data from Northern California

a. Noise Model: The small variances of the 3 dimensional covariance matrix measures error variance. This is needed because we have to account for sensor noise as well as quantization noise.

b. Block Size: From theoretical results, a $4 \times 4 \times 4$ block represents a compromise between performance and speed.

c. Local Means: on 4×4 blocks for each spectral band are removed.

d. Block Diagram: A block diagram of the implement algorithm is shown below.



IMPLEMENTATION WITHOUT MULTIPLICATION

e. Typical Result:

Errors: We can only measure the error between reconstructed and input data and thus

$$E[|\tilde{\underline{s}} - \underline{x}|^2] = E[|\tilde{\underline{s}}|^2] + e[|\underline{n}|^2].$$

We check that

$$E[|\tilde{\underline{s}} - \underline{x}|^2] \leq 2E[|\underline{n}|^2]$$

so that we can claim input quality encoding.

Entropy: We obtain a encoder with a rate of 2.08 bit for $4 \times 4 \times 4$

Walsh Hadamard, ≤ 2.45 including encoding for spectral means.

5. CONCLUSIONS

These are encouraging preliminary results and this work will be prepared for publication in the coming few months.

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APPENDIX 2

SOME REMOTE SENSING APPLICATIONS OF DIGITAL SIGNAL PROCESSING*

V. Ralph Algazi

1. INTRODUCTION

The Remote Sensing of Earth Resources has attracted the interest of a whole spectrum of scientists and engineers, principally since the launch of the LANDSAT-1 Satellite in July 1972. After two years of experience with LANDSAT data, the significant advantages of digital signal processing techniques have become apparent to most users and for most applications.

In this paper we survey briefly the special areas of emphasis in the application of digital signal processing techniques to Remote Sensing: geometric correction, atmospheric correction, information extraction by image enhancement or classification. Some techniques and results are illustrated.

In the study and control of their physical environment, scientists and engineers rely on a broad range of physical principles and techniques to identify and quantify attributes of physical objects. In many situations identification and quantification of attributes can be performed remotely by electromagnetic sensing. The attributes that can be sensed remotely by electromagnetic radiation are spatial distribution (shape and texture), spectral distribution (color), polarization and temporal variations. Since people are sensitive to electromagnetic radiation through their sense of sight, remote sensing has always been used by man in interacting with his environment. Quite recently, considerable emphasis has been given to the systematic exploitation of the whole spectrum of electromagnetic radiation from physical objects, whether directly perceived by man or not, and to Remote Sensing on a large geographic scale through the use of aircraft and satellites. In a large measure a compromise has to be achieved between the detail and accuracy required in the study of physical environment and the geographic extent (or number of measurements) which can reasonably be performed. The promise of Remote Sensing is that it opens new possibilities as to the spatial scale and geographic extent which can be sensed and thus studied or monitored with some limited accuracy.

To use the Remote Sensing of electromagnetic radiation for the study of the Earth, one has to determine in some way whether for the problem at hand there are actually usable corresponding changes in the electromagnetic radiation.

By using specialized sensors one can study in fine detail the whole range of the electromagnetic spectrum from the ultraviolet to microwaves. The basic problem then is to determine whether different objects of interest have sufficiently different spectral properties to permit reliable identification within acceptable errors by Remote Sensing. Different basic properties of materials can

*This work was supported in part by NASA Grant NGL-05-003-404.

be studied in different areas of the electromagnetic spectrum.

As one proceeds from the theoretical or laboratory stage of measuring the electromagnetic radiation properties of natural objects to a field situation one meets a number of problems and practical limitations.

These can be best understood by referring to the diagram of Figure 1. Figure 1 shows a number of unwanted or uncontrolled parameters which modify the attributes of the physical object under study so that the acquired data may differ in significant ways from the ideal. Given these difficulties one has to assess, for each application, whether these unwanted effects are limiting and whether corrective action is possible or needed. The major undesirable effects are the atmospheric absorption which is very significant in parts of the spectrum, the limited resolution which blurs and mixes the spectral radiation from a number of adjacent objects, the errors in radiometric values recorded which make analysis and discrimination difficult or impossible, and the geometric inaccuracies limiting the ability to bring images in registration or in concordance with maps. A significant additional problem is related to the amount of data which has to be manipulated, quantified and analyzed before useful information can be extracted.

A range of digital image processing techniques have been developed in response to these problems and limitations. These techniques may involve deterministic components which integrate a priori knowledge into a model and probabilistics models or measured statistics for unknown or uncontrolled parameters. We shall discuss briefly three areas of major emphasis in the application of digital techniques: geometric correction, information extraction, data compression.

2. GEOMETRIC REGISTRATION AND CORRECTION OF IMAGES

2.1 SCENE REGISTRATION

Registration refers to the ability to superimpose the same geographical picture element on two images of the same scene. Good scene registration is necessary in order to use the multispectral response of objects or to exploit data obtained at different times. For data obtained by a multispectral scanner (MSS) as in LANDSAT (Land Satellite), registration is excellent from spectral band to spectral band on a single pass of the aircraft or satellite. For data acquired on different dates with an MSS or for multispectral or multi-date photographic or television data, registration problems are severe and are handled by techniques discussed below.

2.2 LOCATION CORRECTION

In addition to bringing sets of images into registration, users often wish to locate a point in an image with respect to geographic coordinates so as to make the data compatible with maps. In this case, as in the case of mis-registration some geometric transformation of the acquired data is needed. If a limited geometric correction is adequate, the geometric transformation

can be modeled and a corrected image printed without interpolation or deletion of digital data.^{1,2} For precision geometric processing, the techniques used will combine a priori data, such as spacecraft ephemeris, attitude and rate data, with ground control points to generate a least-squares error correction.^{3,4} Typical results⁴ indicate that 7 ground points are adequate for a LANDSAT frame (185x185 km). Geometric correction will require some interpolation between digital data values. A number of interpolation techniques have been tried³ and this specific interpolation problem is related to the design of continuous two-dimensional filter.⁵

3. INFORMATION EXTRACTION

Once, for a specific application, remote sensing data has been acquired at suitable times and scales, and has been geometrically corrected, the problem remains to extract useful information from that data. What is useful information depends of course on the application.

Two broad classes of techniques have been found useful: 1. Techniques which assist an observer in decision making: false color presentation, image enhancement, multispectral combinations; 2. Techniques in automatic decision making: empirical signature analysis, automatic classification by the use of training sets. We shall characterize these two classes of techniques broadly as image enhancement and automatic classification.

3.1 IMAGE ENHANCEMENT

At this time, machines cannot match man's capability in the many areas of decision making which involve judgment, experience, training, the interpretation of ambiguous data, etc. Even for cases in which a machine can reasonably do the task, it may do so very awkwardly and at a very high cost.

For remote sensing data, in which images are generated from the radiometric values recorded, there are two types of difficulties which need to be overcome before an interpreter can use the data. First, the range of radiometric values displayed as an image may be so narrow that the observer cannot perceive much information at all in the images. The second difficulty is that there may be too much data. For data recorded in up to 3 spectral bands, false color displays are used which assign one color to each of the spectral bands. But more than 3 spectral bands may be involved. LANDSAT-1 has four and some other multispectral scanners go up to 9, 16 or even more spectral bands. These two difficulties can be alleviated by fairly simple computer processing. For instance, contrast stretching, that is to say, increasing the dynamic range of the recorded data before display, is a useful technique which makes perceptible to an observer the recorded data. A more systematic and rational approach can be used for this problem by taking into account the properties of human vision and the statistics of the data to be displayed.⁶ For the problem of too much data one can also use multispectral combination of the data so that a human observer can perceive or utilize all the data pertinent to a specific application. Most of the significant information can be represented into a few equivalent data sets by digitally combining multispectral data.^{7,8} For

LANDSAT-1 data, the following results, Table 1 from Ref. 7 indicate that dimensionality reduction can be performed with very little loss.

Geographical Areas in California

	Bucks Lake	Isleton	East Bay
1 component discarded	.52	0.28	0.81
2 components discarded	1.13	1.21	2.1

Table 1: Mean-Square Error (percent) in a Principal Component Analysis

Note that the optimum transformation used to obtain these results, is closely approximated by a 4 point Walsh Hadamard or Haar Transformation.

3.2 AUTOMATIC CLASSIFICATION

The purpose of automatic classification is to exploit the spectral signatures (and possibly the texture) of features and classes of interest, such as vegetation types, and to provide, without human intervention an estimate of the areas belonging to each class. Here again, the spectral signature obtained in the laboratory may not be directly usable because of extraneous effects and unknown parameters which affect the data under field conditions. The most common practical approach is then to use ground truth. Sample areas of each of the classes to be discriminated are localized in the ground by field crews or by low flying aircraft.

A number of automatic classification schemes have been developed throughout the years and are reported in the technical literature on Pattern Recognition.⁹ What is noteworthy in the field of Remote Sensing is that several equipment manufacturers have developed special purpose digital hardware for the automatic classification of multispectral data quite conveniently and very fast.¹⁰ At this time the techniques which use spectral information only have become fairly routine and are successful in many applications.¹¹ Recently, some attention has been given to the combined use of spectral and spatial information. These techniques may lead to significantly increased classification accuracy in land use or geologic terrain classification.^{12,13,14} Here again some of the Fast Unitary Transforms such as Slant and Walsh-Hadamard show significant promise.¹⁵

4. DATA COMPRESSION

Because of the huge amount of data generated in remote sensing (more than 3×10^7 picture elements on 4 computer compatible tapes for one LANDSAT frame) there is interest in representing this data more efficiently by using

data compression. Since a number of different users exploit the same data it is required that no deterioration of the quality of the data should result from the compression algorithms. Compression ratios of 2:1 to 4:1 are possible using spectral-spatial differential encoding techniques.¹⁶ By using the spectral and spatial correlation of the data for the reduction of quantization noise as well as for encoding, similar results are achievable using Fast Unitary Transforms.¹⁷

5. CONCLUSIONS

Although analog techniques, using photographs for optical processing or multispectral combining, remain important in many Remote Sensing Applications, digital techniques are becoming prevalent for their precision and flexibility. Techniques are motivated and justified by their application to resources and environmental problems. Thus a good interaction of the data processing specialist with the non-engineer user of data is necessary in Remote Sensing. Techniques have to remain computationally simple because of the huge amount of data involved. Although some large digital computers are necessary, substantial results can be obtained with small, but specialized, digital image processing facilities. A fairly natural division of the digital processing and tasks to be performed is shown in Figure 2. Most of the tasks performed by a central facility will require a large computer, smaller computers can be used for some of the same tasks and for all the user oriented activities.

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APPENDIX 3

SEPARATION OF MAN-MADE AND NATURAL PATTERNS IN HIGH-ALTITUDE IMAGERY OF AGRICULTURAL AREAS

ALFRED S. SAMULON

Abstract--A nonstationary linear digital filter is designed and implemented which extracts the natural features from high-altitude imagery of agricultural areas. Essentially, from an original image a new image is created which displays information related to soil properties, drainage patterns, crop disease, and other natural phenomena, and contains no information about crop type or row spacing.

A model is developed to express the recorded brightness in a narrow-band image in terms of man-made and natural contributions and which describes statistically the spatial properties of each. The form of the minimum mean-square error linear filter for estimation of the natural component of the scene is derived and a suboptimal filter is implemented. Nonstationarity of the two-dimensional random processes contained in the model requires a unique technique for deriving the optimum filter.

Finally, the filter depends on knowledge of field boundaries. An algorithm for boundary location is proposed, discussed, and implemented.

1. INTRODUCTION

Two projects designed to explore the possibilities of application of extremely high-altitude imagery to the study of earth resources have borne fruit in the last two years. The Land Satellite (LANDSAT) and Skylab programs have provided thousands of images taken at altitudes of several hundred miles.

Image processing can be a valuable tool in preparing images for viewing, substantially increasing their utility. Several categories of image processing exist.

Three of the most commonly practiced can be described as follows. The first is automatic identification and appropriate labeling of items portrayed in an image [10], [13], [21], [28]. The second is removal from the image of noise and distortion (both radiometric and cartographic) introduced in the recording and transmitting process [23], [28], [33]--[35]. The third consists of methods of distorting an image to improve certain image properties, such as contrast and brightness, or to emphasize certain specific image contents such as edges [1], [28]. While the three categories described are not all inclusive, they are useful in putting in perspective the technique to be described below. The last two methods are not directly related to the goals of the user of the imagery, while the first method assumes the items for which the user is looking can be well defined and specified. In the ensuing sections a new image processing approach is derived and explained. This concept lies between the extremes characterized by the first method on the one hand and the second and third methods on the other hand.

The underlying philosophy can be stated as follows. In many cases automatic labeling of specific items of interest is not possible because of the complexity of the information desired, because the properties of interest are not well defined, or, finally, because a human interpreter presented with the data in a proper form can make better judgments about the contents and significance of the information. It may be possible, however, for the user to specify certain features of the scene recorded in an image that obscure the desired information. Using knowledge of these features and any a priori information about the features of the image which are of interest, it may be possible to remove the obscuring features from the image. Then the processed image can be given to a human interpreter to analyze. In essence, we are taking the point of view that features in an image which are extraneous to the task at hand can be viewed as noise in the classical communication theory sense.

The following work consists of the application of this philosophy to a specific problem. In particular, a processing method is designed and implemented.

The goal of the processing is separation of the man-made and natural patterns in high-altitude imagery of agricultural areas and, in particular, the extraction and display of the natural patterns. For many subjects of earth resource study, the actual planting patterns are of secondary interest. Often of primary interest are soil properties and hydrological properties of the earth [8]. Several factors combine to obscure the soil and hydrological features in agricultural areas. Among these are the vegetation canopy, the large variations in reflectance from field to field depending on the crop in each field, and the limited contrast range of any display medium on which the image is recorded.

The processing method discussed here creates a new image which reveals more clearly than the original image the patterns produced by, and hence the extent of, such things as soil salinity and crop diseases (the natural patterns). Determination of the actual cause of the natural patterns

will require the photointerpreter to use other information, such as crop type, in addition to the enhancement since many different causes can lead to similar patterns. Consequently, actual evaluation of soil conditions must be done by a soil scientist familiar to some extent with the geology, irrigation practices, and history of the region under investigation.

Variations in reflectivity between fields due to differences in crop type are frequently much greater than variations in reflectivity due to crop health and other natural phenomena. Hence removal of planting patterns allows fuller use of the contrast range of the display medium for display of the natural patterns.

The processing method is derived as follows. First, the original image is modeled in Section III as a sample function of a random field (a random process indexed by a two-dimensional parameter). Although this model does not have sufficient complexity to describe accurately the dependence of the reflectivity on the man-made (crop type, row spacing, etc.) and "natural" (crop vigor, soil salinity, soil moisture, etc.) components, the model is adequate to lead to a useful enhancement procedure. The model also represents the spatial properties of the two components. By appropriate transformation of the image, contribution of the two components is made additive. Based on the statistical model, a linear estimator is derived in Section IV which approximates the optimum linear mean-square error estimator of the natural component. The filter requires knowledge of field boundaries. For this reason, in Section V, an algorithm for locating field boundaries is devised. Finally, Section VI contains a discussion of the implementation and results of the overall enhancement algorithm.

Before going into the filtering method, it is useful to describe briefly the imagery used in this work.

II. ERTS IMAGERY

ERTS-1, launched July 23, 1972, was the primary source of pictures used in the work described below [24]. ERTS, which orbits the earth at an altitude between 900 and 950 km, has two kinds of sensors. One is a set of three return beam vidicon tubes, and the other is a multispectral scanner. Since the multispectral scanner produced the images used in the following sections, further description of it is required. The multispectral scanner records the energy in four separate spectral bands from 0.5 to 1.1 μ (0.5 to 0.6, 0.6 to 0.7, 0.7 to 0.8, 0.8 to 1.1 μ). The images produced by the multispectral scanner are in the form of rasters. At each point of the raster a value of brightness is recorded. This brightness corresponds with the amount of energy in the specific spectral band emanating from a 79-meter square area on the ground.

III. THE MODEL

In order to provide the photo interpreter with an image in which only the natural patterns are displayed, we model the image in terms of the contribution of the man-made component and the natural component. This involves modeling the spatial characteristics of man-made and

natural patterns, as well as determining how the recorded image brightness is related to the two components.

A narrow-band spectral image can be viewed as a raster with a real-valued function defined at every point of the raster. Each point (x,y) of the raster corresponds with a point (or more precisely, a small area) in the target scene of the camera or photodetector, and the value of the real-valued function $\phi(x,y)$ is proportional to the amount of electromagnetic energy (in the narrow spectral band) emanating from the corresponding target point.

For the cases of interest here, wavelengths less than 1.1μ , the electromagnetic energy is primarily reflected solar energy [12].

Thus $\phi(x,y)$ is the product of the incident energy $I(x,y)$, the reflectivity $R(x,y)$, and the atmospheric transmissivity $T(x,y)$, plus the atmospheric radiance $N(x,y)$. That is,

$$\phi(x,y) = I(x,y)R(x,y)T(x,y) + N(x,y). \quad (1)$$

It is generally assumed that the percentage of incident energy which is reflected is independent of the amount of incident energy; that is, that $I(x,y)$ and $R(x,y)$ are unrelated.

Now, in order to make further progress, we must cast our problem into a stochastic framework. Consider the following experiment. We pick an area of interest on the earth and place a camera in orbit, aimed such that the camera remains fixed relative to the target. Each trial of the experiment consists of recording the image viewed by the camera. The brightness $\phi(x,y)$ recorded at each point (x,y) is not fixed for all trials but varies according to some probabilistic distribution. Thus each image (experimental outcome) consists of a set of values of a family of random variables indexed by an ordered pair (x,y) . Equivalently, each image is a sample function of a random field (a two-dimensional process to be distinguished from an agricultural field). We then take ϕ , I , T , R , and N to be random fields. In addition, we allow the possibility of an additive noise $\eta(x,y)$ affecting the recorded brightness. This leads to the form

$$\phi(x,y) = I(x,y)R(x,y)T(x,y) + \eta(x,y) + N(x,y). \quad (2)$$

We next assume that the incident illumination is the same over the entire scene. This approximation is quite good in flat agricultural areas where shadows are minimal. Similarly, we assume $T(x,y)$ and $N(x,y)$ constant in each image. We will operate on sections of ERTS images corresponding on earth to approximate rectangles having sides of length on the order of ten miles. Using other imagery the area covered will be smaller. Hence the assumptions that T and N are constant are reasonable. For the sake of simplicity, we now rescale the reflectivity and the "transmissivity, incident radiation product" in such a way that IRT remains unchanged, but IT equals one. This allows us to write

$$\phi(x,y) = R(x,y) + \eta(x,y) + N. \quad (3)$$

At this point we consider the atmospheric radiance, that portion of the light recorded by the sensor which is due to

scattering by the atmosphere. It is, to a first approximation, independent of the ground scene observed by the sensor. Thus, if we assume that the atmosphere is reasonably uniform as a function of horizontal position, then the atmospheric radiance can be considered constant over the entire scene covered by the image. Now, since radiance is always positive (it is a measure of energy), and since atmospheric radiance is assumed constant over an entire image, the atmospheric radiance recorded must be less than or equal to the minimum brightness in an image.

The amount of energy scattered by the atmosphere, as given by Rayleigh's law, is inversely proportional to the fourth power of the radiation's wavelength. Hence atmospheric radiance increases substantially as wavelength decreases. In the spectral bands available from ERTS, the amount of atmospheric scatter is small [17]. Hence atmospheric radiance will be considered negligible for purposes of the present problem. Thus the final model we have to deal with is

$$\phi(x,y) = R(x,y) + \eta(x,y). \quad (4)$$

Now all the information available in the image about the target scene is contained in the $R(x,y)$ term. The reflectivity at any point in the scene depends on a number of factors. The type and vigor of the ground cover, soil background, current soil moisture, current plant moisture, and plant geometry are some, but by no means all, of the relevant parameters. Both crop type and row spacing are determined by man. Hence, for convenience, we call the cumulative contribution to the reflectance of such factors the man-made component. Vigor of the ground cover and soil properties, although affected by man, are examples of essentially natural processes. Again for convenience, we call the total contribution of such factors to the reflectance the natural component. We are interested here in enhancing and displaying the natural component. In order to separate the man-made and natural components, we are required to represent the reflectance R in terms of these two components. A simple model that is mathematically tractable will certainly not be general enough to take into consideration all the factors which determine reflectivity in agricultural areas. Therefore, in order to make progress, we propose the following model that has certain properties consistent with reality and that leads to an effective processing approach, but for which we do not claim general applicability:

$$R(x,y) = \theta(x,y)\zeta(x,y) \quad (5)$$

where $\theta(x,y)$ contains all information about the man-made component and $\zeta(x,y)$ contains all information about the natural component. The motivation for choosing a multiplicative model is the following. In order to apply linear filtering theory, it is mathematically convenient to have a simple model. The most common choice for such models is an additive model. However, for the case of interest here, an additive model defies reality in a fundamental way as is described below. As a model which is slightly more complex,

we consider the multiplicative model. In certain respects this model seems to better approximate reality. As a check of the multiplicative model, an experiment was conducted.

Now we describe the difficulty of an additive model. Reflectance is a quantity which must always be positive. Suppose the reflectance in a certain spectral region of a given crop at a specific level of vigor is very low. For example, most green vegetation, no matter how vigorous, reflects very little in the red portion of the spectrum. Therefore, such vegetation appears very dark through a red filter. Clearly, any decrease in reflectance due to change in vigor must be small, in order that the reflectance remain positive. However, some crops reflect substantially in the red region of the spectrum. A change in their vigor can substantially reduce their reflectivity. Thus equal reductions in vigor correspond to different changes in reflectivity in the two types of crops. Therefore, an additive model defies reality in a fundamental way.

On the other hand, existence of a multiplicative rule would imply that variations in vigor of an essentially dark plant would result in considerably smaller reflectance variations than the reflectance changes resulting from equal changes of vigor in a normally bright plant. As a general rule, this implication of a multiplicative rule conforms with every day experience.

As a further indication of the reasonableness of the multiplicative model, the following experiment was carried out. We demonstrate that two specific properties should hold if a multiplicative model applies. We show that on a sample image these properties do indeed hold.

First we note that at the resolution of high-altitude earth resources imagery, individual lines of a crop cannot be distinguished. In fact, energy recorded at each picture element corresponds with radiation from many rows of crops. We assume that, all other things being equal, a human being will plant his crop uniformly. Furthermore, as previously mentioned, we limit our consideration to flat areas. Hence, were it not for natural disturbances such as variations in soil salinity, the reflectance within a field could be assumed constant.

Now we take the partial differences of the recorded brightness in one direction across the image. Call this direction the x direction. Suppose a multiplicative model were correct. Then after taking partial differences we would obtain

$$\begin{aligned} \phi(x+1, y) - \phi(x, y) \\ = \theta(x+1, y)\zeta(x+1, y) - \theta(x, y)\zeta(x, y) \\ + \eta(x+1, y) - \eta(x, y). \end{aligned}$$

Within any field we have assumed the man-made component to be constant. Therefore, $\theta(x+1, y) = \theta(x, y)$ if $(x+1, y)$ and (x, y) belong to the same field. Thus $\phi(x+1, y) - \phi(x, y) = \theta(x, y)[\zeta(x+1, y) - \zeta(x, y)] + \eta(x+1, y) - \eta(x, y)$. Thus, if the man-made contribution to the reflectivity is low, we expect the differences to be generally small in

magnitude. If the man-made contribution to the reflectivity is large, we expect the differences to be generally large.

Now suppose we first take the logarithm of the image and then take differences. In this case we obtain

$$\begin{aligned} \log [\phi(x+1, y)] - \log [\phi(x, y)] \\ = \log [\theta(x+1, y)] - \log [\theta(x, y)] \\ + \log [\zeta(x+1, y)] - \log [\zeta(x, y)] \\ + \log \left[1 + \frac{\eta(x+1, y)}{\theta(x+1, y)\zeta(x+1, y)} \right] \\ - \log \left[1 + \frac{\eta(x, y)}{\theta(x, y)\zeta(x, y)} \right]. \end{aligned}$$

Again, we use the assumption that the man-made component is constant. Then we obtain

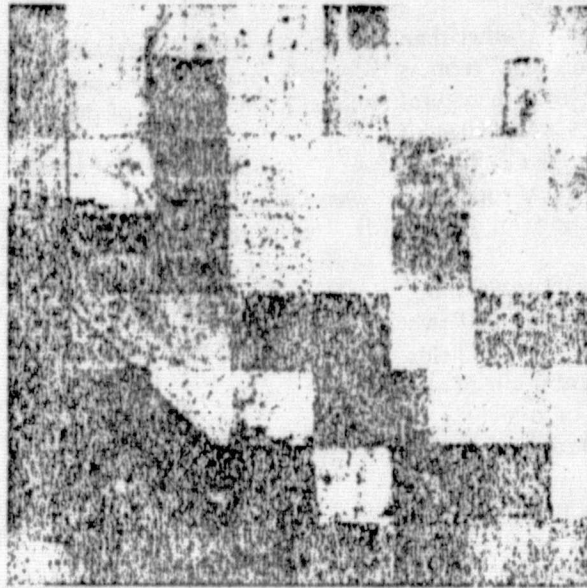
$$\begin{aligned} \log [\rho(x+1, y)] - \log [\rho(x, y)] \\ = \log [\zeta(x+1, y)] - \log [\zeta(x, y)] \\ + \log \left[1 + \frac{\eta(x+1, y)}{\theta(x+1, y)\zeta(x+1, y)} \right] \\ - \log \left[1 + \frac{\eta(x, y)}{\theta(x, y)\zeta(x, y)} \right]. \end{aligned}$$

From the last equation we see that if a multiplicative model applies, the values of the differences should in this case be approximately independent of the man-made component.

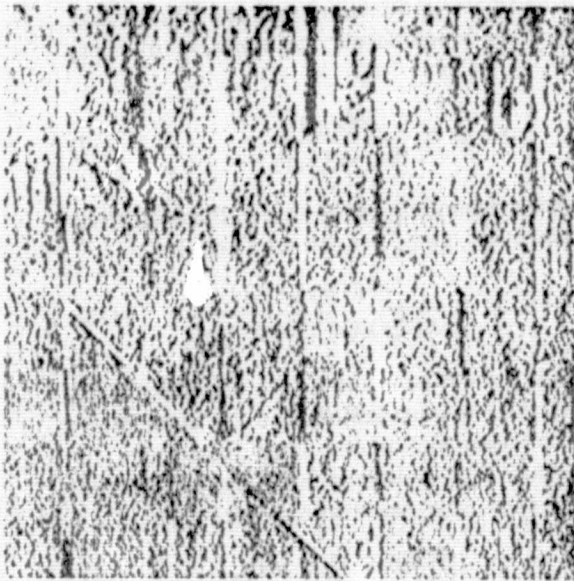
Fig. 1 is an example for which the two properties are indeed satisfied. For this illustration a U2 picture taken over the central valley of California was used rather than an ERTS image. Because ERTS imagery has few picture elements per field (approximately 10×10 in a quarter section), the number of points on the perimeter of each field is a significant percentage of the total number of points in the field. Therefore, since the effect we are looking for does not apply to boundary points, it is difficult to draw a reasonable conclusion from this experiment using ERTS imagery. The original narrow-band (0.69 – 0.79 μ) U2 transparency was scanned by an optical mechanical scanner into an IBM 1800 minicomputer and then displayed on a high resolution cathode ray tube to obtain Fig. 1(a). Fig. 1(b) shows the partial differences in the horizontal direction without first taking the logarithm of the recorded brightness. Fig. 1(c) shows the partial differences after first taking the logarithm. In Fig. 1(b) and 1(c), middle grey represents zero derivative. Whereas in Fig. 1(c) the amount of variation within a field is about the same for every field, the amount of variation in each field in Fig. 1(b) changes in accordance with the brightness of that field in the original image, Fig. 1(a) (the brighter the field in Fig. 1(a), the greater the variation in the corresponding area in Fig. 1(b)).

For the remainder of this paper, we assume the multiplicative model of (5). Combining (4) and (5), we obtain

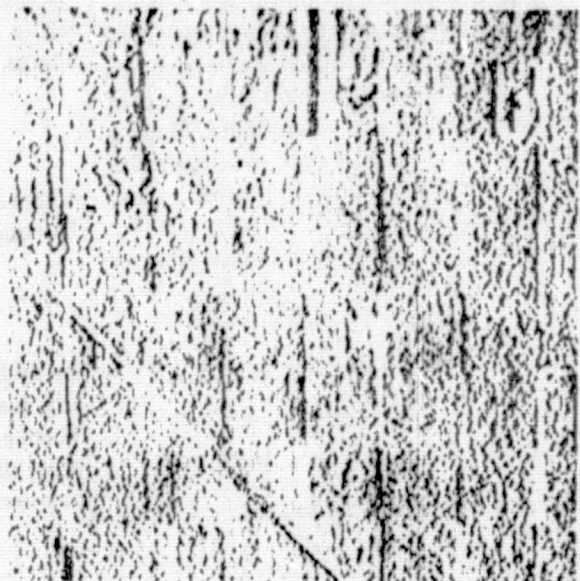
$$\phi(x, y) = \theta(x, y)\zeta(x, y) + \eta(x, y). \quad (6)$$



(a)



(b)



(c)

Fig. 1. (a) Section of U2 near infrared (0.69-0.76 μ) photograph of area in central California. (b) Partial derivative in horizontal direction of image in (a). (c) Partial derivative in horizontal direction of logarithm of image in (a).

Now we make the assumption that both the man-made and natural contributions can be represented as random fields in the statistical sense.

Before describing in further detail the statistical properties of the man-made and natural components, we make some definitions:

$$f'(x, y) \triangleq \log \phi(x, y) \quad (7)$$

$$l'(x, y) \triangleq \log \theta(x, y) \quad (8)$$

$$g'(x, y) \triangleq \log \zeta(x, y) \quad (9)$$

$$n'(x, y) \triangleq \log \left[1 + \frac{\eta(x, y)}{\theta(x, y)\zeta(x, y)} \right] \quad (10)$$

Then we have

$$f'(x, y) = g'(x, y) + l'(x, y) + n'(x, y). \quad (11)$$

Let \bar{g} , \bar{f} , \bar{l} , and \bar{n} be the expectations of g' , f' , l' , and n' , respectively. Now we define

$$g \triangleq g' - \bar{g} \quad l \triangleq l' - \bar{l}$$

$$f \triangleq f' - \bar{f} \quad n \triangleq n' - \bar{n}$$

Therefore, by the linearity of the expectation we have

$$f(x, y) = g(x, y) + l(x, y) + n(x, y). \quad (12)$$

In (12), $g(x, y)$ contains all pertinent information about the

natural patterns. We choose to estimate $g(x, y)$ rather than $g'(x, y)$ for two reasons. First, the constant DC term is irrelevant for finding contours corresponding with natural patterns. Second, estimation of g' requires knowledge of \bar{g} , \bar{l} , and \bar{n} , all of which are unavailable.

Now, in order to design a near optimum linear filter, it is necessary to estimate the correlation functions of f , g , l , and n . We make two observations.

First, what is growing in one field, to a first approximation, does not affect what is growing in any other field. (If two adjacent fields have the same crop, we take the two fields to be one large field.) Therefore, the contribution of the man-made component to the reflectance in one field is independent of the contribution to the reflectance in another field.

Second, the natural disturbances which affect crop reflectance have no preferred direction and a priori can be expected with equal likelihood anywhere in the image. More precisely, we assume that the correlation of the natural contribution at two points on the image depends only on the distance between the points. Equivalently, the correlation function of the natural contribution is assumed translation invariant and rotation invariant. This kind of assumption is a commonly made one when digital filtering is applied to imagery [11], [19]. It is used whenever size is a good parameter to describe a scene, and direction and location have little significance.

Now, for convenience, we introduce some further notation. Let

$$t \triangleq (x, y);$$

$$F(t) \triangleq \text{field to which } t \text{ belongs};$$

$$N \triangleq \text{the number of fields in an image raster};$$

$$f_k(t) \triangleq \begin{cases} 1, & \text{when } t \text{ belongs to the } k\text{th field} \\ 0, & \text{otherwise.} \end{cases}$$

First we consider the correlation function of l , the man-made component. It has already been observed that the man-made component is constant within any field and to a first approximation independent of the man-made component in any other field. Hence

$$E[l(t)l(\tau)] = l^2 \delta_{F(t), F(\tau)} \quad (13)$$

where δ is the Kroneker delta and l^2 is the variance of l .

For the natural component g , the correlation function is translation invariant and rotation invariant based on previous assumptions. The initial part of the derivation of the filter in the next section does not depend on assuming more about g . However, in order to complete the model we look further at the properties of g . We have also observed that natural changes are gradual and aperiodic. Based on these considerations, a correlation function which decays monotonically as a function of distance is proposed. A common choice for a correlation function of this type is an exponentially decaying one.

An exponential correlation function has merit because it depends only on two parameters and makes possible a closed form solution of the problem. Thus we have

$$R_g(t - \tau) = E[g(t)g(\tau)] \approx K e^{-\alpha|t - \tau|} \quad (14)$$

where K is the variance of g , α is the decay constant, and $|t - \tau|$ is the Euclidean distance between t and τ . We assume α is unknown for the present.

The correlation function of n is computed as follows:

$$E[n(t)n(\tau)] = E\{[n'(t) - \bar{n}][n'(\tau) - \bar{n}]\} \quad (15)$$

$$= E[n'(t)n'(\tau)] - \bar{n}^2. \quad (16)$$

Now

$$n'(x, y) = \log \left[1 + \frac{\eta(x, y)}{\theta(x, y)\zeta(x, y)} \right].$$

The noise $\eta(t)$ consists of approximately equal contributions due to sensor noise and quantization error. Therefore, a total error of about one quantization level can be expected. Thus $\theta(x, y)\zeta(x, y)$ is much larger than $\eta(x, y)$ in every image. Therefore

$$n'(x, y) \approx \frac{c\eta(x, y)}{\theta(x, y)\zeta(x, y)} \quad (17)$$

where c is a constant depending on the base of the logarithm. Consequently, since η , θ , and ζ are assumed uncorrelated,

$$E[n'(t)n'(\tau)] \approx \frac{c^2 E[\eta(t)\eta(\tau)]}{E[\theta(t)\theta(\tau)]E[\zeta(t)\zeta(\tau)]} \quad (18)$$

By adding an appropriate constant to the original image, any bias in $\eta(t)$ due to quantization can be eliminated. Then $\eta(t)$ is zero mean and uncorrelated from point to point due to the fact that variations in ϕ tend to be large compared with the size of a quantization level. Hence

$$R_n(t - \tau) \triangleq E[n(t)n(\tau)] \approx \bar{n}^2 \delta_{t, \tau} \quad (19)$$

IV. THE OPTIMUM FILTER

We now have a model of the image to which we can apply the techniques of filtering theory. The contribution to the image of the natural patterns is represented by the g component. Thus it is g we wish to estimate.

We consider estimating $g(t)$ with a linear estimator $\hat{g}(t)$, based on $f(\tau)$ for all τ belonging to T , where T is the set of points in the picture. Thus $\hat{g}(t) = \sum_{\tau \in T} h_t(\tau)f(\tau)$. It was with a linear filter in mind that g and l were defined as they were in the previous section. The concept of transforming essentially nonadditive processes into an additive form and applying linear filtering theory is called homomorphic filtering [25]. Because the processes involved are not all stationary, the filter $h_t(\cdot)$ will be derived for a fixed but arbitrary point t . As error criterion we choose mean-square error. This is just one of a variety of possible error measures [5], [30], [31]. However, application of linear filtering with mean-square error criterion has been effectively applied to many signal processing problems and is at the

heart of both Wiener filtering and Kalman-Bucy filtering [26].

Now using the notation developed in the previous section, the estimation problem can be formalized as follows:

$$\text{choose } h_i(\tau) \forall \tau \in T \text{ and define } \hat{g}(t) \triangleq \sum_{\tau \in T} h_i(\tau) f(\tau) \quad (20)$$

$$\text{such that } E[g(t) - \hat{g}(t)]^2 \leq E[g(t) - \hat{g}(t)]^2 \quad (21)$$

for any $\hat{g}(t)$ a linear estimate of $g(t)$.

In order to determine $\hat{g}(t)$, we invoke the essential idea basic to all problems of linear mean-square error estimation, the orthogonality principle, which states that a necessary and sufficient condition for the optimality of $g(t)$ is that

$$E\{[g(t) - \hat{g}(t)]f(\xi)\} = 0, \quad \forall t, \xi \in T. \quad (22)$$

(See, for example, Davenport and Root [9].) At the outset of the derivation, we will make no assumptions about $g(\cdot)$ except that it be wide sense stationary with zero mean and uncorrelated with l and n . For l and n we will assume the correlation functions specified in the last section.

Thus the derivation which follows will obtain the optimum filter $h_i(\cdot)$ in terms of $R_g(\cdot)$. We now begin our derivation with (22):

$$\text{Eq. (22)} \Leftrightarrow E[g(t)f(\xi)] = \sum_{\tau \in T} h_i(\tau) E[f(\tau)f(\xi)] \quad (23)$$

$$\Leftrightarrow R_g(t - \xi) = \sum_{\tau \in T} h_i(\tau) R_g(\tau - \xi) + \bar{l}^2 \sum_{\tau \in F(\xi)} h_i(\tau) + \bar{n}^2 h_i(\xi) \quad (24)$$

where $F(\xi) \subset T$ is the set of all points in T belonging to the same agricultural field as ξ . In order to proceed further, at this point we break up $h_i(\tau)$ into two components in the following way:

$$h_i(\tau) = \sum_{k=1}^N \mathcal{J}_k(\tau) H_{i,F_k} + p_i(\tau) \quad (25)$$

where

$$F_k = k\text{th field}, k = 1, \dots, N;$$

$$A_k = \text{number of points belonging to } F_k;$$

$$\sum_{v \in F_k} h_i(v) = H_{i,F_k} A_k, k = 1, \dots, N;$$

and

$$\mathcal{J}_k(\tau) = \begin{cases} 1, & \tau \in F_k \\ 0, & \tau \notin F_k. \end{cases}$$

Then returning to (24), taking two sided, two-dimensional z transforms of both sides with ξ as the space domain variable, and taking advantage of the convolution property of the 2-sided z transform, we obtain

$$\begin{aligned} \text{Eq. (24)} \Leftrightarrow P_i(z) &= \frac{S_g(z)}{S_g(z) + \bar{n}^2} z_1^{-x} z_2^{-y} \\ &- \sum_{k=1}^N H_{i,F_k} \left\{ \frac{I_k(z) S_g(z)}{S_g(z) + \bar{n}^2} + \frac{(\bar{n}^2 + \bar{l}^2 A_k) I_k(z)}{S_g(z) + \bar{n}^2} \right\} \end{aligned} \quad (26)$$

where

$$z = (z_1, z_2), \quad t = (x, y)$$

and

$$I_k(z) = \mathcal{Z}[\mathcal{J}_k(\tau)]$$

$$S_g(z) = \mathcal{Z}[R_g(\tau)]$$

$$P_i(z) = \mathcal{Z}[p_i(\tau)].$$

Now from (25)

$$\begin{aligned} \sum_{\tau \in T} p_i(\tau) \mathcal{J}_j(\tau) &= \sum_{\tau \in T} h_i(\tau) \mathcal{J}_j(\tau) - \sum_{k=1}^N H_{i,F_k} \sum_{\tau \in T} \mathcal{J}_k(\tau) \mathcal{J}_j(\tau) \\ &= H_{i,F_j} A_j - H_{i,F_j} A_j = 0, \end{aligned} \quad \text{for } j = 1, \dots, N. \quad (27)$$

Therefore, by performing the summation specified on the left side of (27); substituting for $p_i(\tau)$ the expression obtained by inverse z transforming (26); we obtain N linear equations with N unknowns, H_{i,F_k} , $k = 1, \dots, N$. That is, we have to find a solution to the equation $C = DH$ (H unknown) where

$$H = \begin{bmatrix} H_{i,F_1} \\ \vdots \\ H_{i,F_N} \end{bmatrix} \quad (28)$$

$$C = \begin{bmatrix} \sum_{\tau \in T} \mathcal{J}_1(\tau) \mathcal{Z}^{-1} \left[\frac{S_g(z)}{S_g(z) + \bar{n}^2} z_1^{-x} z_2^{-y} \right] \\ \vdots \\ \sum_{\tau \in T} \mathcal{J}_N(\tau) \mathcal{Z}^{-1} \left[\frac{S_g(z)}{S_g(z) + \bar{n}^2} z_1^{-x} z_2^{-y} \right] \end{bmatrix} \quad (29)$$

$$D = [d_{ij}], \quad i = 1, \dots, N; j = 1, \dots, N \quad (30)$$

in which

$$d_{ij} = \sum_{\tau \in T} \left\{ \mathcal{Z}^{-1} \left[\frac{I_j(z) S_g(z)}{S_g(z) + \bar{n}^2} + \frac{(\bar{n}^2 + \bar{l}^2 A_j) I_j(z)}{S_g(z) + \bar{n}^2} \right] \mathcal{J}_i(\tau) \right\}.$$

There must exist at least one solution of these equations, since the equations are by construction mutually consistent. If D is invertible, the solution is unique and is given by

$$H = D^{-1}C. \quad (31)$$

Now for a specific correlation function, H can be calculated. Then using (26), $p_i(\tau)$ can be specified, and thus by (25), the filter can be determined.

Up to this point in the derivation of the filter, we have used only one assumption about the correlation function of $g(\cdot)$: that it is solely a function of distance. Now we incorporate our assumption that the correlation function of $g(\cdot)$ decreases exponentially with distance.

The set of points for which we know $f(\tau)$ has been earlier defined as T . Suppose we want to estimate $g(t)$, where $t = (x, y)$. For reasons given in the following paragraphs, we consider a suboptimal filter. Let

$$T_x = \{\tau \mid \tau = (x, \tau_2), \quad \tau \in T\}$$

and let

$$T_y = \{\tau \mid \tau = (\tau_1, y), \quad \tau \in T\}.$$

We consider a suboptimal estimate of $g(t)$ of the following form

$$\hat{g}(t) \triangleq \frac{1}{2}[\hat{g}_1(t) + \hat{g}_2(t)] \quad (32)$$

where $\hat{g}_1(t)$ is the optimal linear filter given $f(t) \forall t \in T_x$ and $\hat{g}_2(t)$ is the optimal linear filter given $f(t) \forall t \in T_y$. Now $\hat{g}_1(t)$ is determined under the condition that $R_g(t, \xi) = Ke^{-\alpha|t-\xi|}$. The same derivation applies to $\hat{g}_2(t)$.

There are several practical reasons for limiting ourselves to this suboptimal estimate. First, while it is possible to derive $\hat{g}_1(t)$ and $\hat{g}_2(t)$ (since the one-dimensional z transform of $Ke^{-\alpha|t|}$ is calculable in closed form and is a rational function); the two-dimensional z transform of $Ke^{-\alpha|t|}$ is not calculable in closed form and, therefore, makes impossible calculation of a general expression for the optimal two-dimensional filter as a function of α . For a given set of boundaries, and for a specific α , the optimum two-dimensional filter can be approximated numerically. Based on such an approximation, it is evident that the optimum filter depends on the orientation of each boundary with respect to the square raster of picture elements.

Second, $g_1(t)$ and $g_2(t)$ are themselves optimum estimates for the sets on which they are defined.

Third, implementation of both the optimum and suboptimum filters will depend on knowledge of field boundaries. Finding closed boundaries in two dimensions, however, is a time-consuming and formidable task, particularly when the number of fields is large. Unless most of the boundaries are closed, the two-dimensional filter cannot be implemented since it requires taking averages over entire fields. On the other hand, the one-dimensional filter can be implemented if only most of the boundary points are known, independent of closure of the boundaries, since it requires taking averages over only portions of fields.

Fourth, errors caused by overlooking a boundary point are of a very predictable form for the one-dimensional filter and can be eliminated. (See Section VI for further detail.)

Fifth and last, the mean-squared error obtained by using $\hat{g}(t)$, as given by (32), as the estimator must be less than the average mean-square error obtained by using either $\hat{g}_1(t)$ or $\hat{g}_2(t)$ alone as estimators. In fact, depending on α and the area of the fields, the mean-squared error of $\hat{g}(t)$ can approach half the average mean-square error of $\hat{g}_1(t)$ and $\hat{g}_2(t)$. It should be noted here that the squared error for the suboptimal estimate is for most values of α below 10 percent of the variance of g , and in the worst case is 15 percent of the variance of g . With appropriate refinements of the suboptimal estimate, even in the worst case the mean-square error is less than 10 percent of the variance of g .

Now, in order to determine the optimum filter, we must find the C vector and the D matrix described above. The details are omitted for the sake of brevity. By making two observations, we can easily obtain close approximations to C and D . These observations depend on the actual values assumed by the following parameters of the model.

They are \bar{l}^2/K (greater than 10); the size of a field A_k (approximately 10 samples); the correlation distance $1/\alpha$

of the natural component (less than 10 samples); and K/\bar{n}^2 (greater than 3). Based on these bounds on the parameters, we can make the following two observations.

Observation 1:

$$(\bar{n}^2 + \bar{l}^2 A_k)(e^\alpha + e^{-\alpha} - 2) \gg K(e^\alpha - e^{-\alpha}). \quad (33)$$

Observation 2:

$$e^{-\alpha\gamma} \ll e^{-\gamma} < 1 \quad (34)$$

where γ is defined as

$$\gamma \triangleq \text{arccosh} \{ (\frac{1}{2})[(K/\bar{n}^2 + 1)e^\alpha + (K/\bar{n}^2 - 1)e^{-\alpha}] \}.$$

In order to specify the C vector and D matrix, it is necessary to index the fields. For mathematical convenience, we pick the ordering such that if

$$\tau' \triangleq (t_1, \tau_2') \quad \tau'' \triangleq (t_1, \tau_2'')$$

then $F(\tau') > F(\tau'')$ whenever $\tau_2' > \tau_2''$.

The result of the assumptions and the way we have indexed the fields is that, if $C \triangleq [c_m]$ and $D \triangleq [d_{ij}]$, then

$$c_m = K(e^\alpha - e^{-\alpha}) \sum_{\xi \in a_m} e^{-\alpha|\xi-t|} \quad (35)$$

where $[a_m, b_m]$ is the set of points belonging to field m and T_x and

$$\begin{aligned} d_{ii} &\approx (\bar{n}^2 + \bar{l}^2 A_i) \left\{ (e^\alpha + e^{-\alpha} - 2)(A_i) + 2 \right. \\ &\quad \left. + \frac{2(e^\alpha + e^{-\alpha} - 2)e^{-2\gamma}}{1 - e^{-\gamma}} + \frac{4e^{-\gamma}}{(1 - e^{-\gamma})^2} \right\} \\ d_{ij} &\approx -(\bar{n}^2 + \bar{l}^2 A_j)e^{-\gamma(s_{ij}+1)} \left[1 + \frac{2 - (e^\alpha + e^{-\alpha})e^{-\gamma}}{(1 - e^{-\gamma})^2} e^{-\gamma} \right], \\ &\quad \text{for } i \neq j \end{aligned} \quad (36)$$

where

$$s_{ij} = \min_{\xi \in F_j} \min (|\xi - a_i|, |\xi - b_i|).$$

In order to determine the optimum filter, we need D^{-1} . By observing that the magnitude of elements in the D matrix decreases substantially as one moves away from the main diagonal of the matrix, we are led to the following approximation of D^{-1} based on the binomial expansion.

Let $F = [f_{ij}]$ such that

$$f_{ij} = \begin{cases} d_{ij}, & i = j \\ 0, & \text{otherwise.} \end{cases}$$

Let $G = [g_{ij}]$ such that

$$g_{ij} = \begin{cases} d_{ij}, & |i - j| = 1 \\ 0, & \text{otherwise.} \end{cases}$$

Then

$$D^{-1} \approx F^{-1} - F^{-1}GF^{-1}. \quad (37)$$

We are now in a position to obtain a closed form expression for the suboptimal filter. If $e^{-\gamma}$ is sufficiently

small, we obtain

$$H_i \approx \begin{cases} \frac{K(e^\alpha - e^{-\alpha})}{(\bar{n}^2 + \bar{l}^2 A_i)[(e^\alpha + e^{-\alpha} - 2)A_i + 2]}, & i = m \\ \frac{K(e^\alpha - e^{-\alpha})}{(\bar{n}^2 + \bar{l}^2 A_m)[(e^\alpha + e^{-\alpha} - 2)A_m + 2][(e^\alpha + e^{-\alpha} - 2)A_i + 2]}, & |i - m| = 1 \\ 0, & |i - m| > 1 \end{cases} \quad (38)$$

where $t \in F_m$.

Therefore, by inverse z transforming (26), and substituting into (25)

$$h_i(\tau) \approx \delta_{i,\tau} - \frac{(e^\alpha + e^{-\alpha})\mathcal{J}_m(\tau) - \mathcal{J}_m(\tau + 1) - \mathcal{J}_m(\tau - 1)}{[(e^\alpha + e^{-\alpha} - 2)A_m + 2]} - \frac{(e^\alpha + e^{-\alpha})\mathcal{J}_{m+1}(\tau) - \mathcal{J}_{m+1}(\tau + 1) - \mathcal{J}_{m+1}(\tau - 1)}{[(e^\alpha + e^{-\alpha} - 2)A_m + 2][(e^\alpha + e^{-\alpha} - 2)A_{m+1} + 2]} - \frac{(e^\alpha + e^{-\alpha})\mathcal{J}_{m-1}(\tau) - \mathcal{J}_{m-1}(\tau + 1) - \mathcal{J}_{m-1}(\tau - 1)}{[(e^\alpha + e^{-\alpha} - 2)A_m + 2][(e^\alpha + e^{-\alpha} - 2)A_{m-1} + 2]} \quad (39)$$

for $t \in F_m$ and $\mathbf{1} = (0,1)$.

It should now be pointed out that the filter that has been derived has several desirable properties. The first is that only the first of the four terms depends on t itself. The other three terms depend only on $F(t)$ and hence are constant in any field. This means that the last three terms need be calculated only once in every field, thus reducing the required computation time. Since the first term is a Kronecker delta, it is evident that the estimate in which we are interested is of the form $\hat{g}_i(t) = f(t) - k(F(t))$. Thus the filter only requires calculation of one constant in each field and performance of one subtraction at every point in the picture. The optimum two-dimensional filter can be approximated by the same form. However, for the optimum filter, $k(F(t))$ will depend on the orientation of field boundaries. Furthermore, no closed form expression for k as function of the set of boundaries and of α is possible.

The second nice property of the filter is that it requires information only from five fields to calculate the constant $k(F(t))$; that is, the five contiguous fields such that t belongs to the middle field. Equivalently, the support of the filter is relatively small. This again reduces the computation time. In fact, by inspection of (39) we can see that $k(t)$ depends only on the average values of f in each of three fields and the differences in the values of f at four boundaries.

The third desirable property of the filter is that it does not depend on \bar{l}^2 , K , or \bar{n}^2 . We have eliminated this dependency essentially by one previous assumption. This assumption is that $\bar{l}^2 \gg K \gg \bar{n}^2 e^{-\alpha}$. Consequently, in order to specify the filter we need simply to know boundary locations and the value of α .

V. BOUNDARY LOCATION

In the foregoing section, it was shown that implementation of the optimum filter requires knowledge of field boundaries. Essentially, field boundary location can be viewed as an edge-finding problem. Many methods for attacking such problems have been discussed in the literature. (See for

example, Rosenfeld [29], Montanari [22], and Underwood and Aggarwal [36].)

There are several approaches to the problem. One alternative is human boundary-location. The advantage of this approach is that a human can generally pick out the boundaries quite readily. One of the disadvantages is that the number of boundary points is very large and consequently this method is time-consuming. A further disadvantage is the difficulty for a human to specify the exact location of the boundaries.

Another approach to the problem is to specify some known boundary point, then allow a computer program to proceed along the boundary by specifying certain properties that a boundary must satisfy. For the application of this method to the determination of field boundaries see Kuehn *et al.* [20]. An advantage of this approach is that it is necessary externally to supply only the location of one boundary point. Also, since a known boundary point is initially specified, it is possible to take advantage of such properties of boundaries as being closed. The disadvantage of this approach is that the necessary complexity of such an algorithm leads to a large computation requirement when a large percentage of points lies on boundaries.

A third approach to boundary finding is to specify certain properties of boundaries and test each point independently to determine if it satisfies these properties. Anuta [2], [3] has applied this approach to finding field boundaries. One advantage of this method is that errors do not propagate. That is, if a false boundary point is accepted or a real boundary point is rejected, the decision at neighboring points will not be affected. A further advantage is that such an algorithm can be relatively simple and thus, when a large fraction of points lie on boundaries, can be much faster than a boundary-following algorithm. The disadvantage of the third approach is that real boundary points may be missed and false boundary points may be found.

Because of the resolution of ERTS imagery, a large percentage of points lies on the boundaries (on the order of thirty to forty percent in some images). Furthermore, as will be shown in the next section, the lack or surplus of an occasional boundary point can be accounted for in the filter implementation due to the special nature of the filter. For these reasons and because of the advantages given above, the third approach is taken here.

Two properties are used to define a field boundary. First, it is assumed that at a boundary there will be a sharp change in recorded brightness in at least one spectral band. Second, we assume that in the same spectral band, there will be a large difference in the value of the recorded brightness averaged over several points on one side of a boundary and the value of recorded brightness averaged over several points on the other side of that boundary. The second of the properties is relatively insensitive to noise and hence its use overcomes the problem of noisiness described by Anuta [3].

In an image consisting of brightness values specified on a rectangular grid, every point which lies on a boundary is either horizontally adjacent or vertically adjacent to a boundary point in a neighboring field. Hence a sharp change in recorded brightness at a boundary should occur in either the horizontal or vertical direction even if the boundary is diagonal. Similarly, there should be a large difference in the average values taken in either the horizontal or vertical direction on opposite sides of a boundary. Thus the algorithm we specify tests for boundary points that satisfy the conditions in either direction. The union of sets of points satisfying the conditions in either direction is the set of accepted boundary points.

We specify a function of the image which can be used to measure whether or not a point lies on a vertical boundary. Let

$$q(x, y) = (1/r)[f(x+1, y) - f(x, y)] \cdot \left[\sum_{v=1}^r f(x+v, y) - \sum_{v=0}^{r-1} f(x-v, y) \right] \quad (40)$$

where r is less than the number of samples in one line of one field. It can be shown, based on the model of the image described above, that points not on the boundary of a field generally have values of q close to zero, and that boundary points generally have values of q relatively far from zero. Thus, by picking an appropriate threshold, we can label as boundary points all points having a large $|q|$. All other points can be viewed as nonboundary points. In fact, the threshold level can be chosen interactively by a human.

The technique just described can be used to find points lying on vertical boundaries in one spectral band. By repeating this procedure in the vertical direction, points lying on horizontal boundaries can be found. As has been pointed out previously, the rectangular raster of picture elements implies all boundary points are either horizontally adjacent or vertically adjacent to a boundary point in a neighboring field even if the boundary is diagonal. By

following the same steps in other spectral bands, boundary points not discernible in one spectral band can be found. This is equivalent to making (40) a function of vector valued x and y .

Under certain conditions boundary points can be clustered along lines to improve the boundary-finding algorithm [10], [32].

VI. IMPLEMENTATION AND RESULTS

Before describing the implementation and application of the filter, a refinement should be mentioned.

In Section IV it was shown that the optimal one-dimensional linear estimate can be approximated by subtracting from the logarithm of the picture a function which is constant between every pair of boundary points. In fact it was shown that the constant which is subtracted in each field depends on a number of factors. These factors are the average recorded brightnesses in several contiguous fields and the differences in brightness across several field boundaries. Hence the determination of the correct value to subtract in each field depends critically on knowing the boundary points. If a boundary point is not detected by the boundary finder, or a point not on a boundary is falsely labelled as a boundary point, the wrong constant value may be subtracted from a set of points, resulting in a streak in the filtered image.

It is possible in many cases to compensate for the errors due to inadequacies in boundary detection in one line if the boundary points in the two adjacent lines are found correctly. In most cases, if an error of the type described occurs, the value of the constant which is added will differ sufficiently from the correct value that the brightness of the filtered image on the set of points where the error occurred will be strictly greater or strictly less than the brightness of the filtered image in the two adjacent lines. That is, if filtering is done in the x direction, then either $\hat{g}(x, y) \geq \hat{g}(x, y-1)$ and $\hat{g}(x, y) \geq \hat{g}(x, y+1)$, or $\hat{g}(x, y) \leq \hat{g}(x, y-1)$ and $\hat{g}(x, y) \leq \hat{g}(x, y+1)$ for all x in some interval of line y . Such a condition is unlikely to occur in nature. Consequently, by checking the filtered image for places where this condition occurs and adjusting the constant so that for the new estimate $\hat{g}(x, y)$, $\sum_{x \in I} |2\hat{g}(x, y) - \hat{g}(x, y+1) - \hat{g}(x, y-1)|$ is minimized (where I is the interval over which the error occurs), compensation of boundary detection errors is possible.

The steps involved in implementing the suboptimal filter can now be summarized as follows: 1) take the logarithm of the recorded brightness; 2) find the boundaries; 3) using the boundaries and the logarithm of the image, get horizontal and vertical estimates of the natural component; 4) remove streaks from the horizontal and vertical estimates; and 5) average the horizontal and vertical estimates. Because the filtered images occupy only a small fraction of the contrast range of the display device, a nonlinear contrast stretching algorithm proposed by Algazi [1] is applied to the estimates for display purposes.

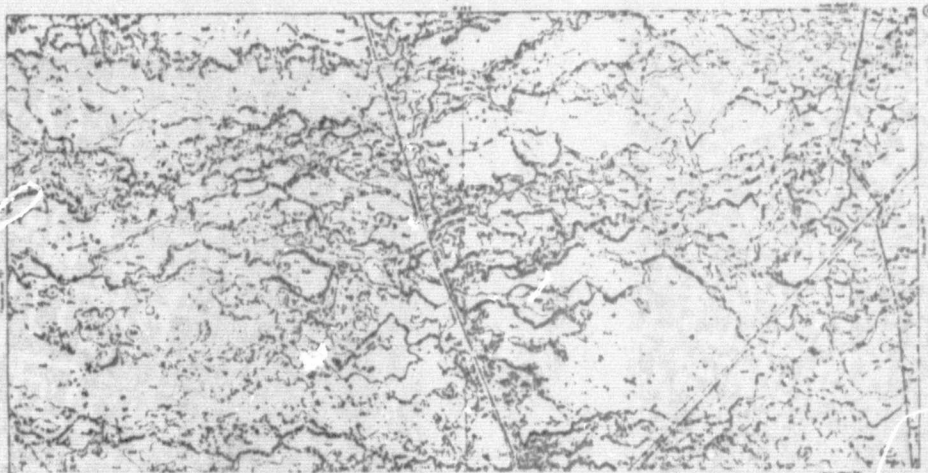
In addition to knowing the boundaries of the fields, the estimator depends on knowing α , the decay constant of the



(a)



(b)



(c)

Fig. 2. (a) Original red component (MSS 5). (b) Filtered $[e^{-\alpha}]_{\text{horiz}} = 0.7$. (c) Soil map of a section of the area shown in (a) and (b).

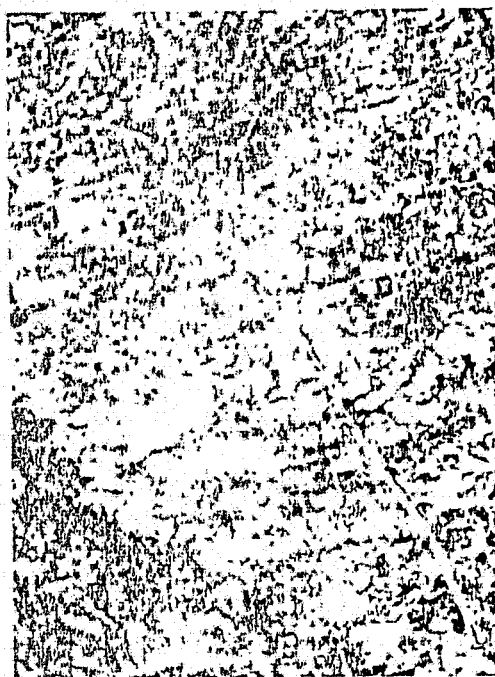
correlation function of the natural component of the image. For ERTS multispectral scanner imagery, the distance between points in the horizontal direction (perpendicular to the satellite's path) is smaller than the distance between points in the vertical direction (parallel to the satellite's path) in a ratio of approximately 5/7. Therefore, the value of α used in the vertical direction should be 7/5 times the horizontal value of α . While the best value of α may vary from image to image, a value of 0.7 for $[e^{-\alpha}]$ horizontal has led to good results for the areas investigated.

An image of an area near Firebaugh, California, where soil salinity is a known problem, was enhanced and is shown in Fig. 2. The height of the image in all the figures is greater than the width due to the fact that for ERTS

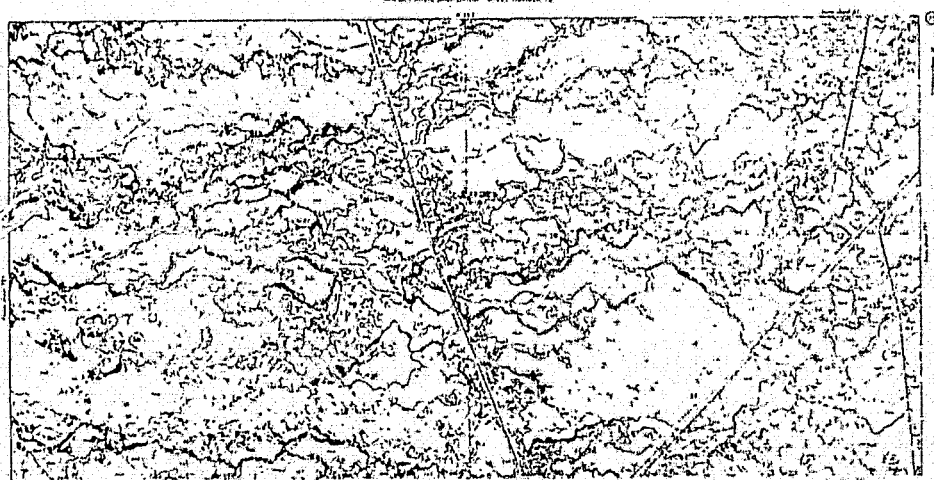
imagery, the vertical distance between picture elements is greater than the horizontal distance. The imagery is not rectangular because as the satellite travels southward, recording succeeding image lines, the earth rotates eastward, causing each new line to be slightly further west than the last. The original, Fig. 2(a), is the red spectral component. Fig. 2(b) is the enhancement with $e^{-\alpha} = 0.7$. The white splotches in the original indicate areas of high soil salinity. In the enhancement the white splotches can be followed across field boundaries and the contours are more readily visible. The area in the center of the image was compared with soil maps by Prof. Huntington of the Soil Science Department of the University of California at Davis, and the contours in the enhancement compared well with those



(a)



(b)



(c)

Fig. 2. (a) Original red component (MSS 5). (b) Filtered $[e^{-\alpha}]_{\text{horiz}} = 0.7$. (c) Soil map of a section of the area shown in (a) and (b).

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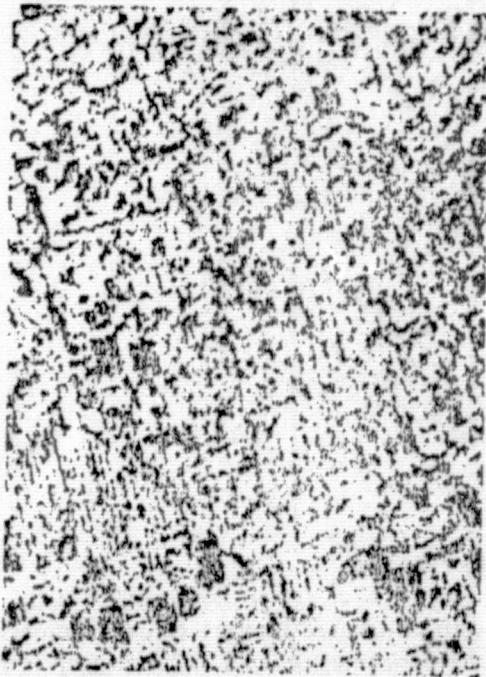
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(a)



(b)



(c)



(d)

Fig. 3. (a) Original near infrared component (MSS 6). (b) Filtered $[e^{-\alpha}]_{\text{horiz}} = 0.7$. (c) Filtered $[e^{-\alpha}]_{\text{horiz}} = 0.001$. (d) Boundaries found using green, red, and near infrared components (MSS 4, 5, 6).

appearing in the map. A map corresponding to the right half of the ERTS picture from just below the middle of the image to three quarters of the way down is shown in Fig. 2(c) (from [37]). The canal and the Firebaugh-Madera road should be used as landmarks in comparing the ERTS picture and the map. One particularly interesting portion of the enhancement is the following. Just below the middle

of Fig. 2(a), on the very right, is a dark field where the natural features are greatly obscured. In Fig. 2(b), the field has disappeared, and the natural patterns can be easily followed.

Fig. 3 shows the dependence of the estimate on various values of α . Fig. 3(a), is the near infrared image of an area in central California. Fig. 3(b) and (c) shows enhancement

CHAPTER 2(b)

REMOTE SENSING-AIDED PROCEDURES
FOR WATER YIELD ESTIMATION

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Special acknowledgement is given to William C. Draeger, Leon Johnson, and Susan Williams who participated in research reported in this chapter.

TABLE OF CONTENTS

	<u>Author</u>	<u>Page</u>
2.000b Introduction	R. Thomas	2b-1
2.100b Approach to Remote Sensing-Aided Water Yield Estimation	R. Thomas	2b-2
2.110b General Estimation Procedures		2b-2
2.120b Water Loss Estimation Models Specific to Given Information Levels		2b-7
2.130b Data Requirements		2b-8
2.140b Necessary Spatial Transforms and Real-Time Water Loss Estimates from the Sampling Framework		2b-13
2.150b Components of the Current RSRP Water Supply Study		2b-14
2.200b Areal Extent of Snow Estimation Using LANDSAT-1 Satellite Imagery	E. Katibah	2b-15
2.210b Introduction		2b-15
2.211b Procedure		2b-15
2.212b Snow Area Extent Inventory Type I		2b-16
2.213b Results of the Snow Area Extent Inventory Type I		2b-28
2.214b Conclusion of Snow Area Extent Inventory Type I		2b-28
2.220b Snow Area Extent Inventory Type II		2b-29
2.230b Library of Snow Cover Conditions		2b-30
2.240b Conclusions and Recommendations for Future Research		2b-41
2.300b Semi-Automatic Analysis of LANDSAT-1 Digital Data for Estimation of Snow Areal Extent	E. Katibah & R. Thomas	2b-27
2.310b Approach and Data Set		2b-47
2.320b Procedure for Semi-Automatic Snow Areal Extent Estimation		2b-47
2.400b Impervious Surface-Parameter Estimation	C. Hay & R. Thomas	2b-49
2.410b Justification and Definitions		2b-49
2.420b Sample Design		2b-50
2.421b Stratification Strategy		2b-51
2.422b Sampling Method for High Flight Imagery		2b-52
2.423b Sampling Method Utilizing LANDSAT Data		2b-53
2.430b Future Work for Impervious Surface Estimation		2b-54

TABLE OF CONTENTS (continued)

	<u>Author</u>	<u>Page</u>
2.500b Development of a Methodology for Evapotranspiration Estimation	S. Khorram & R. Thomas	2b-54
2.510b Introduction		2b-54
2.511b Justification		2b-54
2.512b Background and General Definitions		2b-55
2.520b General Approach		2b-56
2.521b Basic Sample Design and Corresponding Levels of Evapotranspiration Model Sophistication		2b-56
2.522b Other Models Important in the Evapotranspiration Estimation Process		2b-61
2.523b Real-Time Evapotranspiration Estimates from the Sampling Framework		2b-61
2.524b Factors Affecting Evapotranspiration		2b-62
2.525b Available Data		2b-64
2.530b Description and Brief Evaluation of Current Models for Evapotranspiration Estimation		2b-68
2.531b Water Balance		2b-68
2.532b Energy Balance		2b-68
2.533b Aerodynamic Methods		2b-69
2.534b Combination Methods		2b-69
2.535b Empirical Methods		2b-70
2.540b Recommendations for Evapotranspiration Model Applicabilities to Information Resolution Levels within the Remote Sensing-Aided Evapotranspiration Estimation System		2b-73
2.541b Model Recommendations for Level I		2b-73
2.542b Model Recommendations for Level II		2b-75
2.543b Model Recommendations for Level III		2b-76
2.550b Summary and Future Work Related to Evapotranspiration Estimation		2b-76
2.600b RSRP Meteorological Satellite Data Investigations	R. Thomas	2b-84

TABLE OF CONTENTS (continued)

	<u>Author</u>	<u>Page</u>
2.700b Water Supply Model Definition and Performance Evaluation	R. Thomas	2b-85
2.800b Continuing RSRP Grant Water Supply Work	R. Thomas	2b-86
Appendix I Derivation, Description, and Definition of Input parameters for Current Evapotranspiration Estimation and Solar Radiation Equations	S. Khorram	2b-89
Appendix II - Evaluation of Current Models for Evapotranspiration Estimation	S. Khorram	2b-124
Appendix III - Procedure for Measuring Secondary Sampling Unit <u>Ground Plots</u> for Water Loss Estimation	R. Thomas	2b-142
Appendix IV - Procedure for Measuring Secondary Sampling Unit <u>Photo Plots</u> for Water Loss Estimation	D. Huston	2b-168

CHAPTER 2(b)

REMOTE SENSING-AIDED PROCEDURES FOR WATER YIELD ESTIMATION

2.000b INTRODUCTION

The justification for the development of remote sensing-aided water yield estimation procedures lies in the fact that more accurate and timely estimates of that quantity are needed as projected water demands exceed projected available supplies. Close management of the water resource is therefore necessary to maximize usable available water production within the interrelated constraints of other watershed resource objectives such as timber production. Remote sensing data can provide a cost-effective means for obtaining a significant portion of the data needed for more intensive water management. This can be especially the case if water yield estimation procedures are combined with data from other resource inventories and environmental monitoring programs.

The focus of the water supply studies that are being performed by personnel of the Remote Sensing Research Program (RSRP) is such as to develop remote sensing-aided procedures to provide cost-effective, timely, and relatively accurate estimates of components of the hydrologic cycle. Specifically, procedures are being developed for estimating the amount of precipitation, the areal extent and water content of snow, and the amount of evapotranspiration of each major component of a large watershed such as that comprised by the Feather River. Additionally work has started on methods to quantify impervious surface locations and types important in the timing of water yield. Associated methods to quantify watershed pervious surface area and therefore subsurface flow (temporary water loss) mechanisms are being examined for remote sensing applicability.

The projected output from these methods will be used as inputs to current state-of-the-art water yield models operated by the California Federal-State River Forecast Center (RFC) and by the California Cooperative Snow Surveys (CCSS) program. These models were defined and described in detail in Chapter 2 of the May, 1974 Grant Report. Precision and accuracy improvements in water yield estimation made possible by remote sensing-aided water parameter estimates will be quantified.

Assessment of the performance of water yield models currently being used in California is a coordinated effort between the Davis and Berkeley NASA Grant groups. The effort consists firstly of a further analysis of model driver variables, such as total effective precipitation, snow water content and evapotranspiration. The second aspect of this analysis involves the hydrologic model performance analysis. This effort consists

of three parts: (a) performance (accuracy, precision, timeliness) of current water supply models in relation to current drivers and data types, (b) performance of current models in relation to drivers whose data values are defined through remote sensing-aided estimation systems developed by RSRP and Davis groups, and (c) performance of models (yet to be developed) that have been modified to make most effective use of remote sensing data.

These performance studies are being conducted in cooperation with the California agencies involved. Due to the complex nature of data flow and computer-human interaction in developing water yield forecasts the NASA Grant participants will, at the request of the RFC, encourage hydrologic model analysis work review, response, and advice from the state organizations involved.

The remote sensing-aided system will also be used by RSRP in simple water balance equations to provide estimates of water supply. These water supply estimates will be used as checks on the accuracy of our watershed water loss estimates. The ultimate check on both state hydrologic model and RSRP water balance equations will be actual gaged streamflow.

2.100b APPROACH TO REMOTE SENSING-AIDED WATER YIELD ESTIMATION

2.110b General Estimation Procedure

The basic approach to remote sensing-aided water yield estimation involves a multistage, multiphase sample of three increasingly resolved information data planes. The products are estimates of several water loss parameters which may be combined with an estimate of basin water input to provide watershed water yield estimates. Alternatively, the water loss variable estimates may be substituted into more complex hydrologic models such as those of RFC and CCSS to aid in accurate determinations of water yield. Water loss-related variables currently being considered by RSRP include snow water content, evapotranspiration, and impervious surface area. The first and third variables are primarily correlated with temporary water loss while the second represents a "permanent" water loss from the system.

The proposed approach to the estimation of the magnitude of water yield parallels that of other remote sensing-aided resource inventories developed by RSRP. Examples would be the timber resource inventory approaches analyzed for cost-effectiveness in Chapters 7 and 8 of this report.

The first step in the procedure involves a stratification of the water source area into basin or subbasin areas of hydrologic significance. For instance, the Feather River Watershed, focus of the NASA Grant Study and source watershed for the California Water Project, may be divided into its component branch basins and/or stratified based on water quantity related elevational zones.

After stratification, the general water loss variable estimation procedure is given in Figure 2.1.1b. That sample design for estimating water loss quantity is given in the right side of that figure while the left side is devoted to formulation of models and data sets to estimate water loss at each stage and phase of the sample design. A definition of sample design terminology is given in Figure 2.1.2b.

A first level of information resolution is developed by merging LANDSAT, NOAA (meteorological satellite), and digitized topographic data planes. Vegetation, terrain, and meteorological information are defined for a convenient base resolution element, in this case the LANDSAT pixel. Based on the information associated with each base resolution element an estimate of the water loss variable of interest is made for that location. The appropriate water loss estimation equation, defined as an Order 1 model in Figure 2.1.1b must be able to perform adequately on the information available from this first data level. Adequate performance is defined in the context of the sampling procedure as a generation of water loss variable estimates strongly correlated to actual ground-measured or ground-based estimates of water loss for the variable of interest.

After water loss estimates are made for a given water loss variable for each level 1 resolution element, a grouping of resolution elements into primary sample units (PSU's) is performed. The standardized size and shape of the PSU's is selected so as to minimize total first sample stage variance among PSU's for all watershed water loss variables to be simultaneously estimated. Alternatively, the PSU geometry may be optimized to minimize first stage estimate variance for another resource parameter, such as timber volume, for which information utilized in the water inventory was originally collected.

Based on the water loss variability among PSU's, a sample of these units is selected in each water related stratum for further sampling. Selection may be with probability proportional to estimated amount of water loss within given PSU's for a given loss variable or for a combination of variables. Thus sampling is on the average directed to areas of higher water loss. PSU selection with equal probability can be considered an alternative where subsampled information is used to estimate water quantities for other water loss variables.

The chosen PSU's are then overflowed with medium and large scale photography as in the case of other resource inventory procedures. Each medium scale photograph within a selected PSU provides the framework for a definition of a secondary sampling unit (SSU). The SSU's form a series of large scale photographic plots within each PSU centered at the medium scale photo center. The photographic SSU data along with nearby snow course and ground station calibrated meteorological satellite data provide the second level of information resolution.

Figure 2.1.1b

Hydrologic Modelling: Quantification of Time Specific Water Runoff Loss to Snow, Evapotranspiration, and Subsurface Flow

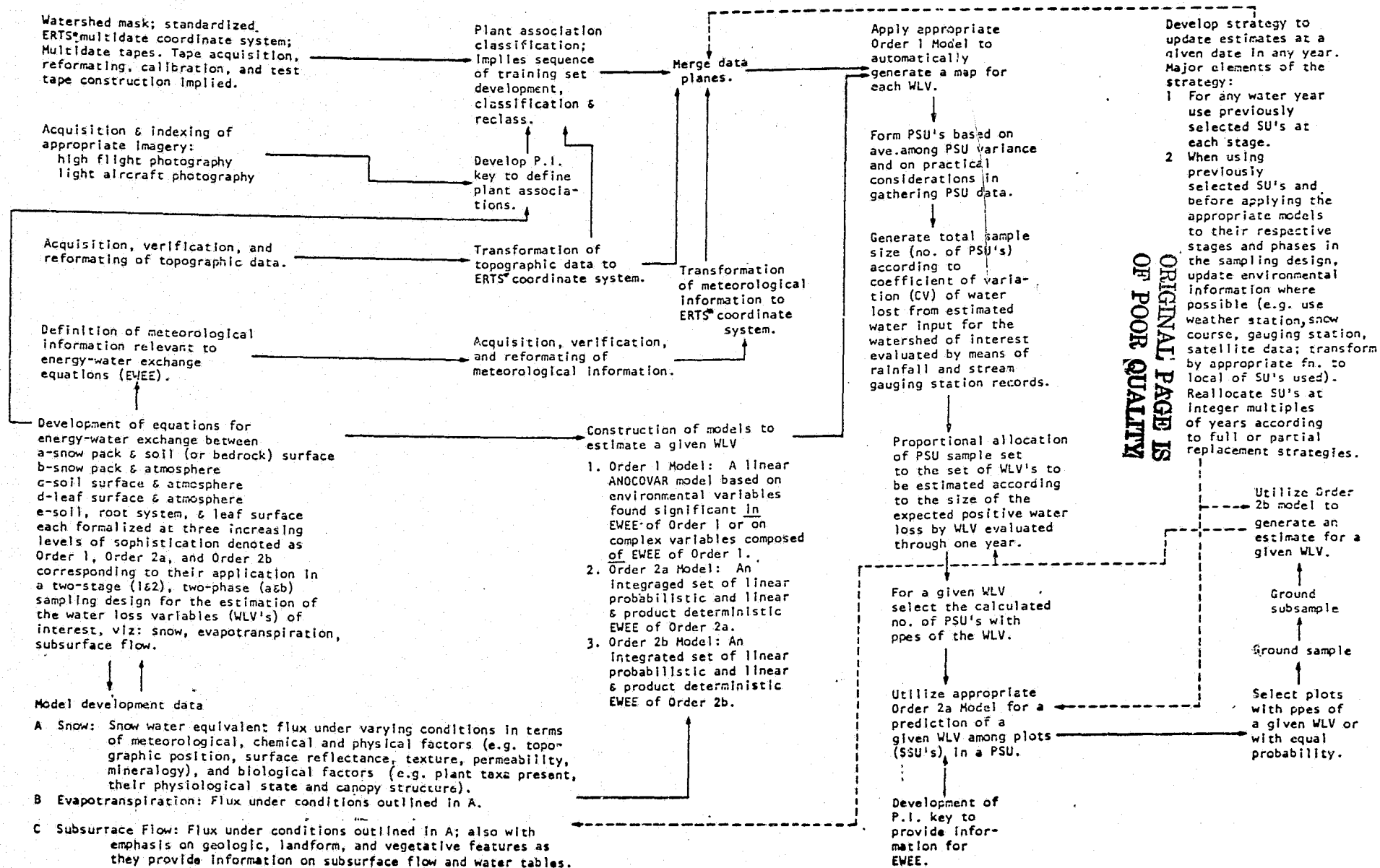
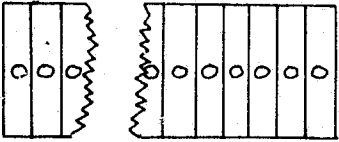
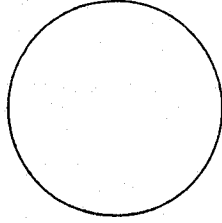
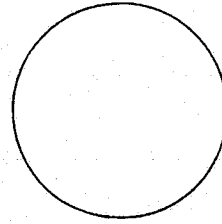
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OF POOR QUALITY

FIGURE 2.1.2b - WATER LOSS SAMPLE DESIGN TERMINOLOGY

Information Level	Sample Unit	Sample Design Level	Comments
1	PSU	Stage 1	All PSU's in watershed have water loss estimates made based on a summation of water loss estimates for LANDSAT resolution elements occupying each PSU. A sample of the PSU's is selected for further sampling
		Multistage portion of sample design	
2	Photo SSU	Stage II	
		Phase 1	All SSU's within a selected PSU have water loss estimates made based on surface characteristics interpreted from the photography
		Multiphase or double sample portion of sample design	
3	Ground SSU	Phase 2	Ground measurements resulting in ground-based water loss estimates are made for a sample of the photo SSU's
			

At the SSU stage of the sampling design, much more specific information concerning local vegetation canopy composition and geometry, soil characteristics, and local climatic conditions is available (see Appendix IV) as opposed to that obtainable from information at level 1. Thus water loss models employing more data types and more refined data are used to generate water loss estimates for each PSU. These equations are denoted as Order 2a models in Figure 2.1.1b. Estimates at this stage will be more expensive on a unit basis than for first stage (PSU) water loss variable estimates.

Lastly a sample of the photo SSU's is selected for further detailed measurement on the ground. This sample is based on the "within PSU" second stage sample unit constraints. Either probability proportional to size of the water loss estimate or equal probability selection can be employed for this phase of the sampling design.

For each of the SSU's selected, detailed ground measurements are made of vegetation canopy geometry, color, species composition, etc. as well as of soil and litter-organic debris physical and chemical characteristics (see Appendix III). The detailed data from this third level of information will then drive very sophisticated Order 2B water loss estimation models. Since estimates of water loss will be for the entire ground area of the SSU photo plot, this third stage unit (TSU) will actually comprise a double sample of the SSU's. The cost of acquiring data for the ground sample, that is for information level three, is the most expensive of all levels.

Figure 2.1.1b describes this double sample in terms of a photo SSU first phase and a ground SSU second phase. Note that the photo SSU is simultaneously the second sample stage and the first sample phase in the basic two stage, two phase water loss estimation sample design. The double sample allows the development of a specific least-square relationship between the more precise and accurate water loss ground SSU-based estimates and the photo SSU estimates. Such relationships can be employed to calibrate photo SSU estimates where no ground data were obtained. In addition, ground to photo least-square relationships can be developed to calibrate vegetation and soil surface quantifications made on aerial photography. Such calibrated photo data give rise to more accurate water loss estimates at the second stage of the sample design (information level 2).

In sample design overview and with reference again to Figure 2.1.2b, it is clear that information levels 1, 2, and 3 specify the data plane at which a sampling operation takes place. Obtaining and processing information at increasingly higher information level numbers is exponentially more costly. Thus a smaller and smaller watershed area is sampled as the information level number increases.

The full watershed estimate of water loss for a given water loss variable can then be developed by first using the ground based water loss estimate to calibrate the SSU estimate based on photo data. The

calibrated SSU estimates can then be expanded to the PSU stage by employing the SSU selection weights developed earlier. Finally, PSU water loss estimates can be expanded over the pertinent stratum and then to the entire watershed by applying the PSU selection weights originally calculated. In this way, a cost-effective combination of an increasingly smaller sample of more precise and more expensive information levels can be utilized to give basin-wide watershed estimates.

2.120b Water Loss Estimation Models Specific to Given Information Levels

The sampling procedure just described differs from previous RSRP remote sensing-aided inventory systems in several ways. The first, apparent from Figure 2.1.1b, is that for water loss prediction at each stage or phase of the sample design, moderate to complex mathematical models based on known energy-water exchange relationships are employed. These models are based on the type, resolution, and amount of data available from the information level relevant to the sample stage or phase in question.

These mathematical water loss models are formalized at three increasing levels of sophistication according to the increase in type, amount, and detail of information proceeding from information level 1 to level 3. They are denoted as Order 1, 2a, and 2b models corresponding to their application in the two stage (1&2), two phase (a&b) sample design.

The Order 1 models, designed to operate on information available from level 1, are presently formulated as linear statistical models. These equations are often referred to as analysis of covariance (ANOCOVAR) models, as they provide for both qualitative and quantitative independent predictor variables and their interactions. Statistical tests are available to test for the significance of estimated parameters corresponding to these variables. Thus predictor variables may be included or excluded for a basin or sub-basin area depending on their statistical significance or non-significance to precise water loss prediction respectively.

Water loss estimation equations for level 2 information, denoted as Order 2a models in Figure 2.1.1b, are composed of a combination of linear-product deterministic as well as linear statistical relationships. The deterministic equations, generally not stochastic (probabilistic) in nature, are designed to physically model actual energy-water exchange processes. The resulting increased sophistication of the Order 2a models over the Order 1 is intended to take advantage of the specific vegetation canopy and surface information available from the SSU photo plots. The result is a tendency for more environment-specific, accurate, and precise water loss estimates than obtained for corresponding PSU's from level 1 information.

Order 2b models differ from Order 2a models primarily in the complexity of the deterministic equations and in the sophistication of the predictor variables utilized. The Order 2b relationships are designed to give the most complete and accurate estimate of water loss in the multistage, multiphase sample design as they may utilize detailed ground measurements for information level 3. Tests of predictor variable significance in Order 2a and 2b models are more difficult than for just the linear statistical case found in the Order 1 model. These significance tests must be based in part on the information loss resulting from predictor variable or complex expression exclusion from the physical relationships of the Order 2a and 2b models.

The predictor variables and structure of the water loss estimation models of Order 1, 2a, and 2b are based on the development of relationships for energy-water exchange identified in the literature and in RSRP research. These energy-water exchange relationships are defined between the following environmental surfaces: (a) snow pack and soil surface (or bedrock surface), (b) snow pack and atmosphere, (c) soil surface and atmosphere, (d) leaf surface and atmosphere, and (e) soil, root system, and leaf surface. Each of these relationships is formalized at three increasing levels of sophistication corresponding to information available to Order 1, 2a, and 2b models, respectively. Each relationship is specific to the energy-exchange process for the water loss variable of interest: snow water content, evapotranspiration, and impervious surface area.

Predictor variables based on these energy-water exchange relationships utilized in the water loss estimation relationships (Order 1, 2a, 2b) may be simple or complex. An example of a simple independent variable is average daily temperature. Complex predictor variables consist of mathematical relationships, physical or probabilistic, which themselves predict the value of an independent variable. Moreover, the juxtaposition of independent variables and their interactions in the Order 1, 2a, and 2b models is dependent on the defined energy-water exchange relationships. That is, the physical location of variables or variable expressions in the water loss prediction models may be determined from analysis of the energy-water exchange relationships.

2.130b Data Requirements

The energy-water exchange equations necessitate the need for a broader data type base than utilized in other resource inventories. This statement is true both for developing data needed in the water loss prediction equation and for that information required to drive the remote sensing-aided water loss estimation system operationally.

The scope of these data requirements is summarized in Table 2.1.3b. Initial information types and procedures for data collection are given for ground SSU plots and photo SSU plots in Appendices III and IV respectively.

TABLE 2.1.3b - WATER LOSS ESTIMATION DATA TYPES

Information Source	Derivable Data	Highest Fetch Rates	Remote Sensing-Aided Water Loss Estimation Information Level of Application*
LANDSAT (hardcopy and digital data)	1. Vegetation types 2. Terrain types 3. Snow types	Every 18 days	1
NOAA (hardcopy and digital data)	1. Canopy-top temperature 2. Snow surface temperature 3. Cloud-top temperature correlated to precipitation 4. Generalized snow presence data	Twice Daily, 9-10 am and pm LST	1,2,3
Large-medium scale photography	1. Vegetation canopy composition and spatial configuration 2. Ground surface zone characteristics	1 to several times yearly	2
Supplemental Imagery	1. Optional additional canopy and temperature quantification for large area energy flow modeling	multiyear to several times yearly	2,3
Ground Plot Data	1. Canopy geometry 2. Ground surface zone characteristics	multiyear	3
Topographic Data (USGS quadrangles or stereo planigraph output)	1. Elevations	once	1,2,3
Ground Meteorological Station Data USDC, Environmental Data Service; by State	Temperature: Ave. maximum Ave. minimum Ave. Departure from normal Highest (with date) Lowest (with date) degree days Precipitation: Total Departure from normal Greatest day (with date)	Monthly	1,2,3

[illegible]

2b-10

Table 2.1.3b (cont)

Information Source	Derivable Data	Highest fetch rate	Remote Sensing-Aided Water Loss Estimation Information Level of Application*
U.S.F.S. Plumas National Forest WB form 612-17	Elevation Dry bulb temperature Wet bulb temperature Wet bulb depression Relative humidity (max,min) Fuel stick moisture Wind direction Wind speed Precipitation Average cloud cover	Daily	
USDA, Forest Service	Total incoming solar radiation	Daily	
Department of Water Resources	Total incoming solar radiation	Daily	
Department of Water Resources (Boulder Creek)	Class "A" evaporation pan data	Monthly for June, July, Aug., Sept.	
Literature	Total incoming solar radiation and some other parameters relating to solar radiation	Daily	
Snow courses and automatic snow sensors	1. Snow depth 2. Snow density 3. Snow water content	Courses: monthly during season Sensors: minutes	2,3
Stream gauging stations	1. Stream flow volume 2. Water yield data	Hourly to Daily	1,2,3
Literature	1. Albedo 2. Energy-water exchange data		1,2,3

* Legend: 1 = information level 1: LANDSAT level of information resolution
 2 = information level 2: large scale photograph level of resolution
 3 = information level 3: ground level of information resolution

Table 2.1.3b (cont)

Information Source	Derivable Data	Highest fetch rate	Remote Sensing- Aided Water Loss Estimation Information Level of Application*
U.S.F.S. Plumas National Forest WB form 612-17	Elevation Dry bulb temperature Wet bulb temperature Wet bulb depression Relative humidity (max,min) Fuel stick moisture Wind direction Wind speed Precipitation Average cloud cover	Daily	
USDA, Forest Service	Total incoming solar radiation	Daily	
Department of Water Resources	Total incoming solar radiation	Daily	
Department of Water Resources (Boulder Creek)	Class "A" evaporation pan data	Monthly for June, July, Aug. Sept.	
Literature	Total incoming solar radiation and some other parameters relating to solar radiation	Daily	
Snow courses and automatic snow sensors	1. Snow depth 2. Snow density 3. Snow water content	Courses: monthly during season Sensors: minutes	2,3
Stream gauging stations	1. Stream flow volume 2. Water yield data	Hourly to Daily	1,2,3
Literature	1. Albedo 2. Energy-water exchange data		1,2,3

* Legend: 1 = information level 1: LANDSAT level of information resolution
 2 = information level 2: large scale photograph level of resolution
 3 = information level 3: ground level of information resolution

The data types recommended for use within the remote sensing-aided water loss estimation system must be available to varying degree throughout many regions of the world in order to maximize the utility of the proposed technique. In addition they must be cost-effectively obtained, ideally in the context of other data application programs, at fetch-rates utilizable in water loss estimation models.

2.140b Necessary Spatial Transforms and Real-Time Water Loss Estimates From the Sampling Framework

The proposed water loss estimation approach differs from other remote sensing-aided inventories in two additional ways. First, spatial transforms must be developed to distribute coarsely defined information, such as meteorological satellite pixel data, and/or sparse point information to small resolution elements at a given information level, for example LANDSAT pixels. The second difference is that of reporting time period. While estimates of total timber volume, for instance, may be required at three, five, and higher year intervals, estimates of water yield may be required for quarterly, monthly, weekly, daily, and even hourly periods. This high frequency inventory situation requires a cost-effective turnover of sample units and application of the set of spatial transforms cited above. The result is a real-time update of variables important in water loss estimation at selected sample unit locations.

Spatial transforms and real-time estimation are discussed in detail in sections 2.522b and 2.523b, respectively, for the case of evapotranspiration estimation. Briefly, spatial transformations involve microclimatic functions to transform data from, for example, a NOAA meteorological pixel, into information specific to each of the approximately 100 corresponding LANDSAT pixels. In the case of meteorological satellite information, a calibration is made of transformed meteorological data by double sampling the resulting transformed pixel information with corresponding ground data station values. The type of microclimatic spatial transformation function cited above is also used to transform ground meteorological data to SSU locations. Such transformed ground station values can be used as a check on transformed, ground calibrated meteorological satellite data specific to given SSU's.

The second type of spatial transform is that used to take the canopy-top meteorological data generated by the first spatial transform type (horizontal) and generate a vertical profile of the meteorological parameter in question. This vertical profile of magnitude (for example, temperature or relative humidity) will be based on SSU canopy and surface geometry. These canopy meteorological variable profiles will be used to provide the detailed information necessary to drive Order 2a and 2b water loss estimation models.

Real-time estimation involves the repeated use of photo ground SSU data over a period of several months to several years. A subset of the originally selected SSU and associated PSU units is deactivated

in a given year and a new set chosen to replace it. This process is a form of partial replacement sampling. Through use of the horizontal and vertical transformations just discussed, real-time meteorological sample unit-specific values are estimated using previously defined canopy and surface geometry-composition characteristics. Real-time estimates of water loss may then be made using the existing multistage, multiphase sampling framework.

2.150b Components of the Current RSRP Water Supply Study

In addition to the development of the multistage, multiphase sampling design for water loss estimation discussed in section 2.100b, specific technique development for remote sensing applications supporting this design is progressing. Included here is the development of cost-effective remote sensing-aided methodologies for watershed snow areal extent estimation, snow water content estimation, evapotranspiration estimation, and impervious surface estimation. Each of these techniques is utilized in the context of the remote sensing-aided water loss estimation system outlined in Figure 2.1.1b. Each of the resulting water variable estimates will be employed in current California Department of Water Resources water supply models to document water yield performance improvements resulting from remote sensing data.

Associated with these techniques is the development of microclimatic transformation functions just discussed. As stated there, this transformation function analysis involves the integration of meteorological data, particularly meteorological satellite information, with LANDSAT and more conventional remote sensing and ground data planes. Such integration promises significant gains in the usefulness of remote sensing information to renewable resource inventory and monitoring.

The following sections of Chapter 2b deal successively with (1) manual approaches to snow areal extent estimation, (2) semi-automatic snow areal extent estimation, (3) manual and potentially semi-automatic impervious surface area estimation, (4) semi-automatic evapotranspiration estimation, (5) preliminary meteorological satellite data work, and (6) current water supply model definition and performance evaluation. Appendices I and II document and evaluate evapotranspiration models relevant to remote sensing applications. Appendix III gives data collection instructions for ground SSU's defined in the water loss estimation sampling design, while Appendix IV documents data collection instructions for photo SSU's in the same sample design.

Procedures for snow water content estimation based in part on LANDSAT data are given in the context of a cost-effectiveness analysis in Chapter 6. That chapter is especially important from the standpoint of an economic measure of value for remote sensing applications to water supply quantification.

2.200b AREAL EXTENT OF SNOW ESTIMATION USING LANDSAT-1 SATELLITE IMAGERY*

2.210b Introduction

One of the most easily detected of all resources from Earth orbiting satellites is snow. Investigators have proposed that relationships could be developed between snow-cover depletion and water runoff (Leaf, 1969) and in more specific terms, between snow-cover depletion and snow water content. It is also deemed possible and cost-effective to relate areal extent of snow in specific vegetation, elevation and aspect relationships to the actual snow water equivalent for a given area using snow survey data collection systems similar to those in use in many areas (Thomas; 1974, Thomas and Sharp, 1974). Since it is highly probable that relationships such as the ones described above could be developed using areal extent of snow to provide the major portion of the information to be used in water runoff equations, techniques had to be developed which would provide fast, economical, and accurate estimation of this parameter. The following research deals with the development of techniques for estimation of snow areal extent.

Using conventional aerial photography as the data base for obtaining snow areal extent information would obviously prove extremely costly if this necessitated covering entire watersheds on a sequential basis. Satellite imagery, more specifically LANDSAT-1 satellite imagery, could provide the data base, relatively inexpensively and on a repetitive basis. In order to quantify areal extent of snow, techniques were developed under this NASA grant which analysed the imagery for areal extent of snow based on reflectance and such parameters as elevation, vegetation and aspect. The first technique described provides a preliminary analysis of such research using a relatively simple procedure which none-the-less provides some very solid quantitative results. A second technique is also described which utilizes a more complex set of additional data to aid the analyst in the snow areal extent estimation. In conjunction with the two techniques, a description of a method substantially lower costs for such a survey has been included under the title of "Library of Snow Cover Conditions."

2.211b Procedure

The estimation procedures described in the following pages are based upon analyses of imagery defined by artificial units (grids) and environmental units (coincident units dealing with vegetation, aspect, and elevation, respectively). These techniques differ substantially from the snow mapping approach reported in the literature (Barnes and Bowley, 1969; Rango and Foster, 1975; Rango Salomonson, and Foster, 1975, Wiesnet, 1974), where the snowpack boundary is delineated directly. The procedures developed at the Remote

*The work reported in this section is considered to be complementary to, and not duplicative of, work currently being performed by NASA-Goddard personnel under the title "GSFC Snow Mapping ASVT."

Sensing Research Program, during water supply studies sponsored by this NASA grant, allow the image analyst to make decisions in discrete units of the imagery as to the areal extent of snow based upon such factors as density and type of vegetative cover, elevation, aspect, actual reflectance of the snowpack, and by inference (i.e. by the presence of directly observable snowpack). These techniques also provide for the direct application of appropriate statistical methods for the estimation of the true areal extent of snow, as well as providing a means of determining the precision of that estimate.

LANDSAT-1 imagery in the form of simulated color infrared enhancements of bands 4, 5, and 7 was used for the interpretation procedures. These enhancements were made from individual 9-1/2 inch LANDSAT-1 black-and-white positive transparencies and combined using a technique developed at the Remote Sensing Research Program (Katibah, 1973). Consequently, enhanced imagery of just that portion of the LANDSAT-1 frame desired could be produced with excellent quality. Use of this technique also provided original enhancements directly on negative color film so that high quality reflection prints could be produced for interpretation purposes.

2.212b Snow Areal Extent Inventory Type I

During the spring of 1973, the LANDSAT-1 satellite provided essentially cloud-free coverage of the Feather River Watershed on April 4, May 10, and May 28. On these days (or at the most, two days thereafter) random transects were flown across the watershed using a 35 mm camera to acquire large scale photography that could be used as an aid in determining the actual snow condition on the ground (i.e. "ground truth").

To estimate the areal extent of snow, the LANDSAT-1 images were gridded with image sample units (ISU's), each equaling 400 hectares (1 hectare= 2.47 acres) (Figures 2.21b, 2.2.2b, 2.2.3b and 2.2.4b). These image sample units were then transferred to the large scale photography where applicable. The image sample units on the large scale photography were coded as follows:

<u>Code</u>	<u>Snow Cover Class</u>	<u>Midpoints</u>
1	No snow present within the ISU	0
2	0-20% of ISU covered by snow	.10
3	20-50% of ISU covered by snow	.35
4	50-98% of ISU covered by snow	.74
5	98-100% of ISU covered by snow	.99

The gridded LANDSAT-1 images were then interpreted, sample unit by sample unit, and coded using the following method to account for vegetative cover and density and to some degree aspect, elevation and slope as they impact snow cover.

Scale matched simulated color infrared enhancements of LANDSAT-1 imagery were produced for April 4, 1973; May 10, 1973, May 28, 1973 and also for August 31, 1972 in reflection print form. The April and May dates represent the snowpack and were gridded, while the August 1972 date, representing a cloud-free summer image, was not gridded. The purpose of the August date was to provide a clear aerial view of actual ground relationships of vegetation/terrain features. The August date was superimposed with each of the snowpack dates using a mirror stereoscope. By blinking first one eye and then the other, the image analyst could observe what conditions actually occurred on the ground in the image sample unit he was interpreting for snow-pack. Obviously, this technique capitalizes on the human image analyst's ability to synthesize large amounts of pertinent data and quickly arrive at a decision.

The image analyst, using this technique, spent three hours training himself to interpret the LANDSAT-1 imagery. The April 4th date comprising 2218 image sample units, was subsequently interpreted in nine hours, the May 10th date (2050 image sample units) in six hours, and the May 28th date (2013 image sample units) in three hours. The decrease in interpretation time can undoubtedly be related to the increasing experience of the analyst and the decreasing snowpack.

The LANDSAT-1 interpretation results were compared to the coded large scale photography where applicable. Tables 2.2.1b, 2.2.2b, and 2.2.3b summarize the interpretation test results. The sample unit by sample unit interpretation of the LANDSAT-1 image was then used to find the estimate for the areal extent of snow in the watershed. Totals for each of the individual snow cover classes were found and multiplied by 400 hectares, the area of each image sample unit on the ground. This gave the acreage for each class; these values were then multiplied by the appropriate snow cover class midpoints to give the total acreage of snow in each class. Finally, these totals were added to give the estimated areal extent of snow. See Table 2.2.4b.

The areal extent of snow thus calculated was based solely upon the LANDSAT-1 interpretation results. To correct this estimate, the image sample units where snow areal extent "ground truth" was obtained (from large scale aerial photographs) were compared with the same image sample units on the LANDSAT-1 imagery. The relationship between the snow areal extent values on these corresponding LANDSAT-1 and "ground truth" sample units is the basis for the application of the ratio estimator statistical technique (Cochran, 1959). This technique not only provides a correction for the original interpretation estimate, but also allows for an estimate of the precision of this technique through the application of confidence intervals. The confidence intervals around the areal extent of snow estimates were calculated for four different levels of confidence, 99%, 95%, 90% and 80%, for comparative purposes. The confidence intervals are expressed in hectares and in the form of allowable error (Table 2.2.5b). The ratio estimator statistics as well as the manner in which the confidence intervals and allowable errors were calculated are shown in Appendix I.

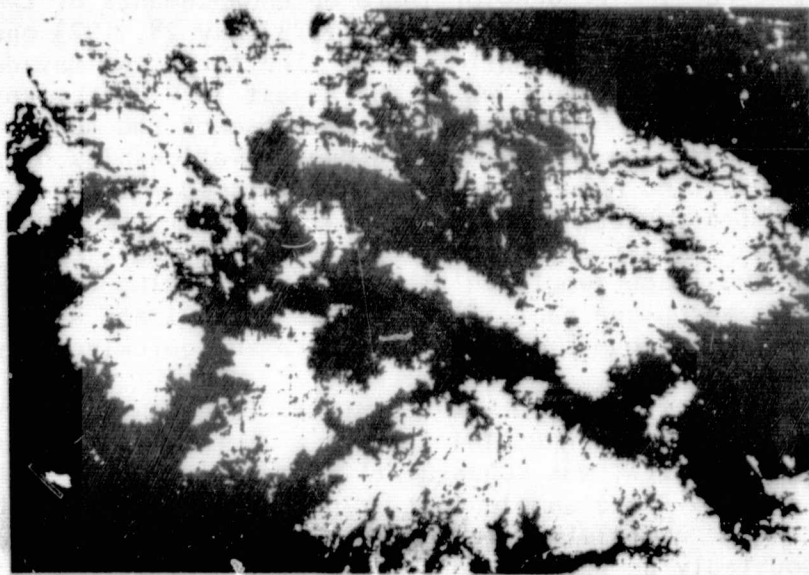


Figure 2.2.1b April 4, 1973 LANDSAT-1 simulated color infrared enhancement. Image sample units (grids) = 400 hectares each.

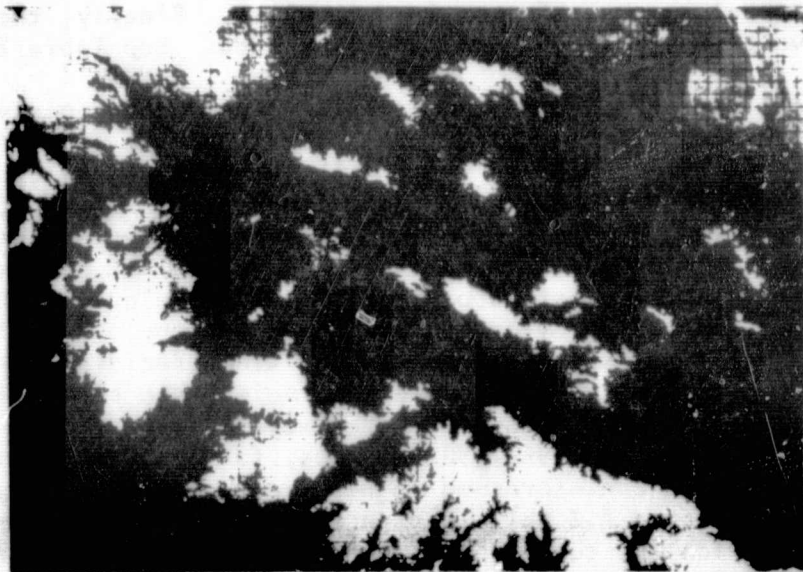


Figure 2.2.2b May 10, 1973 LANDSAT-1 simulated color infrared enhancement. Image sample units (grids) = 400 hectares each.

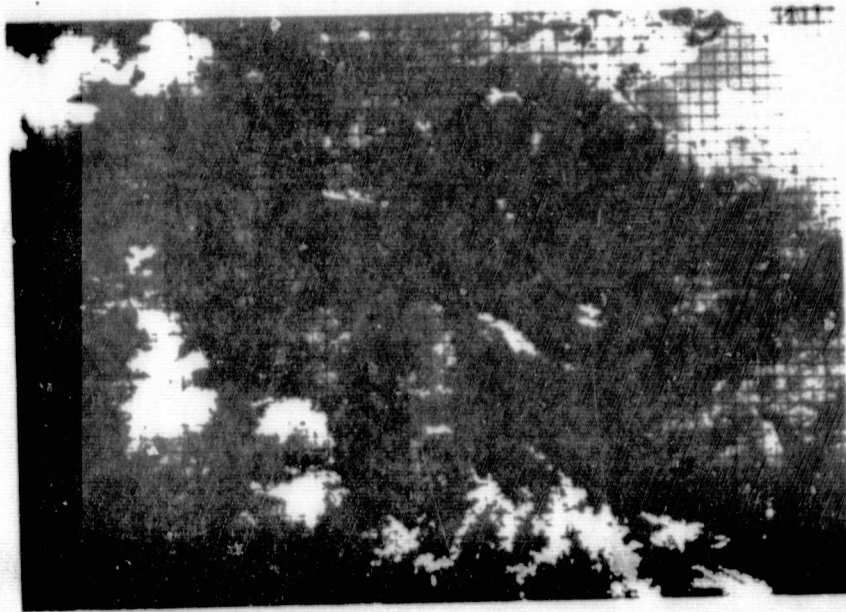


Figure 2.2.3b May 28, 1973 LANDSAT-1 simulated color infrared enhancements. Image sample units (grids) = 400 hectares each.

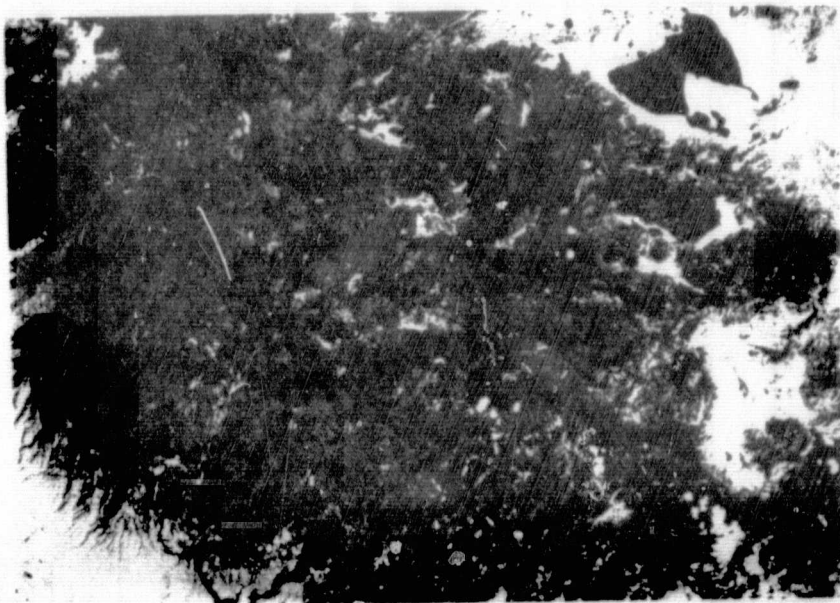


Figure 2.2.4b August 31, 1972 LANDSAT-1 simulated color infrared enhancement. Cloud-free summer image.

2b-20

2b-20

2b-20

2b-20

2b-20

2b-20



TABLE 2.2.2b

MAY 10, 1973 LANDSAT-1 AREAL EXTENT OF SNOW INTERPRETATION RESULTS (ALSO LISTING OF x_i 's AND y_i 's)

		Large Scale Photo Data									
		Snow Cover Classes									
		1		2		3		4		5	
LANDSAT-1 Image Data	Snow Cover Classes	1	0	4	0	4					
		2			40	13	40	2			
		3			140	1	140	9	140	1	
		4					296	2	296	3	
		5						396	5	396	8

x_i = sample LANDSAT-1 estimate of the number of hectares of snow per cell by snow cover class = (snow cover class midpoint)(400 hectares).

y_i = sample large scale photo estimate of the number of hectares of snow per cell by snow cover class = (snow cover class midpoint)(400 hectares).

f = interpretation frequencies

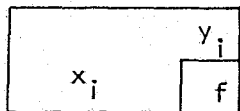


TABLE 2.2.3b

MAY 28, 1973 LANDSAT-1 AREAL EXTENT OF SNOW INTERPRETATION RESULTS (ALSO LISTING OF x_i 's AND y_i 's)

		Large Scale Photo Data									
		Snow Cover Classes									
		1		2		3		4		5	
LANDSAT-1 Image Data	Snow Cover Class	1	0	3	0	4					
		2	40	1	40	16	40	1			
		3			40	2	140	9	140	296	3
		4					296	2	296	4	
		5							396	4	

x_i = sample LANDSAT-1 estimate of the number of hectares per cell
by snow cover class = (snow cover class midpoint)(400 hectares)

y_i = sample large scale photo estimate of the number of hectares of snow
per cell by snow cover class = (snow cover class midpoint)(400 hectares).

f = interpretation frequencies

x_i	y_i
	f

TABLE 2.2.4b

SUMMARY OF RESULTS
AREAL EXTENT OF SNOW ESTIMATION

		April 4, 1973	May 10, 1973	May 28, 1973
LANDSAT-1 estimate of the areal extent of snow	x	511,378	205,768	60,516
Estimate of the true areal extent of snow	Y_R	501,355	195,644	57,847
Standard deviation of the areal extent of snow estimate	$\sqrt{V(Y_R)}$	12,776	14,526	17,126
Population ratio estimator	R	.9804	.9509	.9559
Total number of hectares inventories		879,642	813,014	798,340
Total number of image sample units inventories	N	2,218	2,050	2,013
Total number of image sample units sampled	n	80	52	49

TABLE 2.2.5b

CONFIDENCE INTERVAL AND ALLOWABLE ERROR STATEMENTS

AREAL EXTENT OF SNOW ESTIMATION

Level of Confidence	April 4, 1973		May 10, 1973		May 28, 1973	
	Confidence Level	AE	Confidence Interval	AE	Confidence Level	AE
99%	$477,649 \leq Y_R \leq 545,107$	6.13%	$166,897 \leq Y_R \leq 244,638$	19.87%	$14,566 \leq Y_R \leq 106,466$	79.43%
95%	$485,940 \leq Y_R \leq 536,816$	5.07%	$176,601 \leq Y_R \leq 234,935$	14.91%	$26,075 \leq Y_R \leq 94,958$	59.54%
90%	$530,575 \leq Y_R \leq 532,651$	4.24%	$181,423 \leq Y_R \leq 230,112$	12.44%	$31,778 \leq Y_R \leq 89,242$	49.68%
80%	$494,858 \leq Y_R \leq 527,898$	3.30%	$186,899 \leq Y_R \leq 22,463$	9.64%	$38,252 \leq Y_R \leq 82,781$	38.49%

TABLE 2.2.6b
CHI-SQUARE TEST FOR APRIL 4, 1973 DATA

Null Hypothesis: Ho: The observed values (O_i) come from the same distribution as the expected values (E_i)

Alternative Hypothesis: H_i : The observed values do not come from the same distribution as the expected values

Significance Level: 5%

Test Statistic Under the Null Hypothesis: $\sum_{i=1}^k \left[\frac{(O_i - E_i)^2}{E_i} \right] \sim \chi^2_{k-1}$; where $k-1$ = the degrees of freedom

Full Class Data Summary

Class	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$
1	7	6	.1667
2	11	13	.3077
3	10	7	1.2857
4	13	21	3.0476
5	39	33	1.0909

$$\sum_{i=1}^k = 5.8992$$

$$\text{Table Value} = \chi^2_{5-1, .05} = \chi^2_{4, .05} = 9.49$$

Conclusion: The null hypothesis is accepted since the calculated value of 5.8992 is less than the table value of 9.49.

Lumped Class Data Summary:

Class	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$
1	7	6	.1667
2	11	13	.3077
3	10	7	1.2857
4	52	54	.0741

$$\sum_{i=1}^k = 1.8342$$

$$\text{Table Value} = \chi^2_{4-1, .05} = \chi^2_{3, .05} = 7.81$$

Conclusion: The null hypothesis is accepted since the calculated value of 1.8342 is less than the table value of 7.81.

TABLE 2.2.7b - CHI-SQUARE TEST FOR MAY 10, 1973 DATA

Test at 5% significance level

Null Hypothesis: H_0 : The observed values (O_i) come from the same distribution as the expected values (E_i)

Alternative Hypothesis: H_1 : The observed values (O_i) do not come from the same distribution as the expected values (E_i)

Test statistic under the null hypothesis: $\sum_{i=1}^k \left[\frac{(O_i - E_i)^2}{E_i} \right] \chi^2_{k-1}$; where $k-1$ - the degrees of freedom

Class	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$
1	8	4	4.000
2	15	18	.5000
3	11	13	.3077
4	5	9	1.7777
5	13	8	3.1250

$$\sum_{i=1}^5 = 9.7104 = \text{calculated value}$$

$$\chi^2_{5-1, .05} = \chi^2_{4, .05} = 9.49 = \text{table value}$$

\therefore Since the calculated value (9.7104) is more than the table value (9.49) the null hypothesis is rejected.

Class	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$
1	7	4	2.25
2	18	22	.7272
3	14	12	.3333
4	10	11	.0909

$$\sum_{i=1}^4 = 3.4014 = \text{calculated value}$$

$$\chi^2_{4-1, .05} = \chi^2_{3, .05} = 7.81 = \text{table value}$$

\therefore Since the calculated value (3.4014) is less than the table value (7.81), the null hypothesis is accepted.

TABLE 2.2.8b - CHI-SQUARE TEST FOR MAY 28, 1973 DATA

Test at 5% significance level

Null Hypothesis: H_0 : The observed values (O_i) come from the same distribution as the expected values (E_i).

Alternative Hypothesis: H_1 : The observed values (O_i) do not come from the same distribution as the expected values (E_i)

Test statistic under the null hypothesis: $\sum_{i=1}^k \frac{(O_i - E_i)^2}{E_i} \chi^2_{k-1}$; where $k-1$ = the degrees of freedom

Class	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$
1	7	4	2.500
2	18	22	2.7272
3	14	12	.3333
4	6	11	2.2727
5	4	0	0.0000
			$\sum_{i=1}^5 = 5.5832$ = calculated value

$$\chi^2_{5-1, .05} = \chi^2_{4, .05} = 9.49 = \text{table value}$$

\therefore Since the calculated value (5.5832) is less than the table value (9.49), the null hypothesis is accepted

Class	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$
1	8	4	4.0000
2	15	18	.5000
3	11	13	.3077
4	18	17	.0588
			$\sum_{i=1}^4 = 4.8665$ = calculated value

$$\chi^2_{4-1, .05} = \chi^2_{3, .05} = 7.81 = \text{table value}$$

\therefore Since the calculated value (4.8665) is less than the table value (7.81), the null hypothesis is accepted

It is desirable to check and see if the values in the snow cover class from the LANDSAT-1 image data come from the same statistical probability distribution as the values in the snow cover classes from the large scale photography data. If they come from the same distribution it may be expected that our estimation procedure will provide good results. If there were also a way to lump snow cover classes to improve the indications that the two sets of values came from the same distribution, this would give some idea on how to improve the estimation procedure in the future. To perform such probability distribution likeness tests, a Chi-square statistic,

$$\chi^2 \sim \sum_{i=1}^k \frac{(O_i - E_i)^2}{E_i}, \text{ was used. The values in the snow cover classes from the}$$

large scale photo data were designated as the expected values (E_i), since they were assumed to be "ground truth". The values in the snow cover classes from the LANDSAT-1 image data were designated as the observed values (O_i). For each date a Chi-square test was run, using the data as recorded versus the data with snow cover classes 4 and 5 combined, to see if an improvement in class widths could be realized.

2.213b Results of the Snow Areal Extent Inventory Type I

The results of the type I inventory are summarized in the following tables. Tables of interpretation results, statistical computations (including areal extent of snow estimates, standard deviation of areal extent of snow estimate, population ratio estimator, etc.), confidence intervals and allowable errors, and Chi-square test results are found in the following pages. Tables 2.2.1b, 2.2.2b and 2.2.3b with April 4, May 10, and May 28 interpretation data respectively. Table 2.2.4b deals with the results of the ratio estimator statistic on all three dates. Table 5 deals with the confidence intervals and allowable errors associated with the areal extent of snow estimates on all three dates. Tables 2.2.5, 2.2.7 and 2.2.8 deal with the results of the Chi-square tests on April 4, May 10, and May 28 respectively.

2.214b Conclusion of Snow Areal Extent Inventory Type I

Improvement in the snow areal extent inventory, type I as it is currently done is possible by increasing the sample size and by optimizing the image sample unit size.

The Student's-t statistic reaches its smallest value when the degrees of freedom (sample size minus one) are approximately 120. In subsequent inventories using this approach, each date for which large scale aerial photography is flown should have approximately this number of image sample units definable.

One of the items that should be investigated is the optimum size of the image sample unit. Several approaches are possible as well as a combination of all of them. For instance, image sample unit size may be plotted against interpretation time, standard deviation or standard deviation times cost to determine the optimum image sample unit shape and size under those constraints.

The one improvement that by itself can substantially decrease the width of the confidence intervals (and consequently the allowable errors) is that of decreasing the sample standard deviation. As already shown, the April 4 data had the smallest standard deviation, the May 10 data had the next smallest and the May 28 data had the largest. The reason for this progressive increase in sample variance most likely can be attributed to the decrease in the snow pack over the three dates. The image analyst's ability to classify seems to be related to the proportion of snow cover; however the majority of the variance may not be due to the analyst, but rather to a natural state of greater snow areal extent variability among sample units over an area defined as a watershed.

The Chi-square test indicated that on all dates the experimental set-up was adequate except for May 10. Substantial improvements in matching the corresponding value distributions of the large scale photography data and the LANDSAT-1 image data were realized by lumping snow cover classes 4 and 5. This indicates that the analyst had difficulty in separating snow areal extent class 4 areas from class 5 areas. If the snow cover classes were to be redistributed (0-20%, 20-40%, 40-60%, 60-80%, 80-100% for example) the analyst might realize an improvement in his ability to classify snow cover conditions. Provided the analyst's ability to classify snow cover conditions did improve, then it would be expected that the sample variance for each set of interpretation results would go down, and consequently, the width of the confidence interval would decrease (as well as the allowable error, AE) given constant sample sizes and confidence levels.

2.220b Snow Areal Extent Inventory Type II

The method of estimating snow areal extent previously described, provided a fast, low cost, and accurate method of conducting this type of inventory. This snow areal extent inventory type II represents a refinement in which accuracy gains should offset the longer interpretation time and higher initial cost anticipated.

The type II inventory stratifies the watershed into homogeneous environmental units defined by vegetation/terrain, aspect, and elevation. These three factors were chosen because of their unique relationship to snow dynamics. Other parameters such as isohyet lines, slope, nearness to a meteorological baseline, etc., could also have been used but were not at this

time. It is believed, but remains to be verified, that elevation will provide information on snow areal extent and snow water content behavior that is unique to that particular environmental unit.

Each set of unique environmental units is plotted on acetate overlays on which the watershed boundary has been delineated. The watershed boundary provides the control for placement of these units during plotting and also for the final interpretation process. The end-product is a series of acetate maps (overlays), each clearly partitioning a unique segment of the environment with relation to snow.

As in the type I inventory, "ground truth" will again be acquired through the use of large scale aerial photography. Since we are working with 1973 data presently, some image sample units used for the testing and training procedures will have to be taken from outside of the Spanish Creek Watershed. However, it is believed that snow/environmental unit relationships will not change due to the similarity between the Spanish Creek Watershed and the Feather River Watershed. A statistical approach such as the ratio estimator may again be used and/or a new technique such as a regression estimator could be tried depending on the final sample design.

Such questions as whether the image sample units will be based on the environmental or on some optional image sample unit size (research on which is discussed in the previous section on the type I inventory) will have to be determined. The outcome of such a decision will have a major influence as to the statistic design used for final estimation procedures.

2.230b Library of Snow Cover Conditions

One of the possible avenues for lowering the expense of estimating snow areal extent is to develop a library of snow cover conditions, in which the appearance of the snow pack is compared between low altitude photography and satellite (LANDSAT) imagery, along with other relevant data on an image sample unit (ISU) basis. This approach could virtually eliminate the yearly low altitude photography requirement once the library is complete. Figures 2.2.5b and 2.2.6b serve as a preliminary example to illustrate how the low altitude photography compares with the LANDSAT-1 imagery for several different snow cover conditions.

Parameters which represent relevant snow cover related data that might be included in such a library are: (1) the general time period (by month) in which a particular image sample unit took on a specific appearance with regard to snow cover, (2) data dealing with the magnitude (based on average precipitation), temperature (freezing or thawing), and date of the previous winter storm which affected the appearance of the image sample unit, (3) the environmental units (based on unique combinations of vegetations/terrain, aspect, and elevation) which compose a given landscape and thus affect the way in which snow cover is imaged, and (4) the snow water content

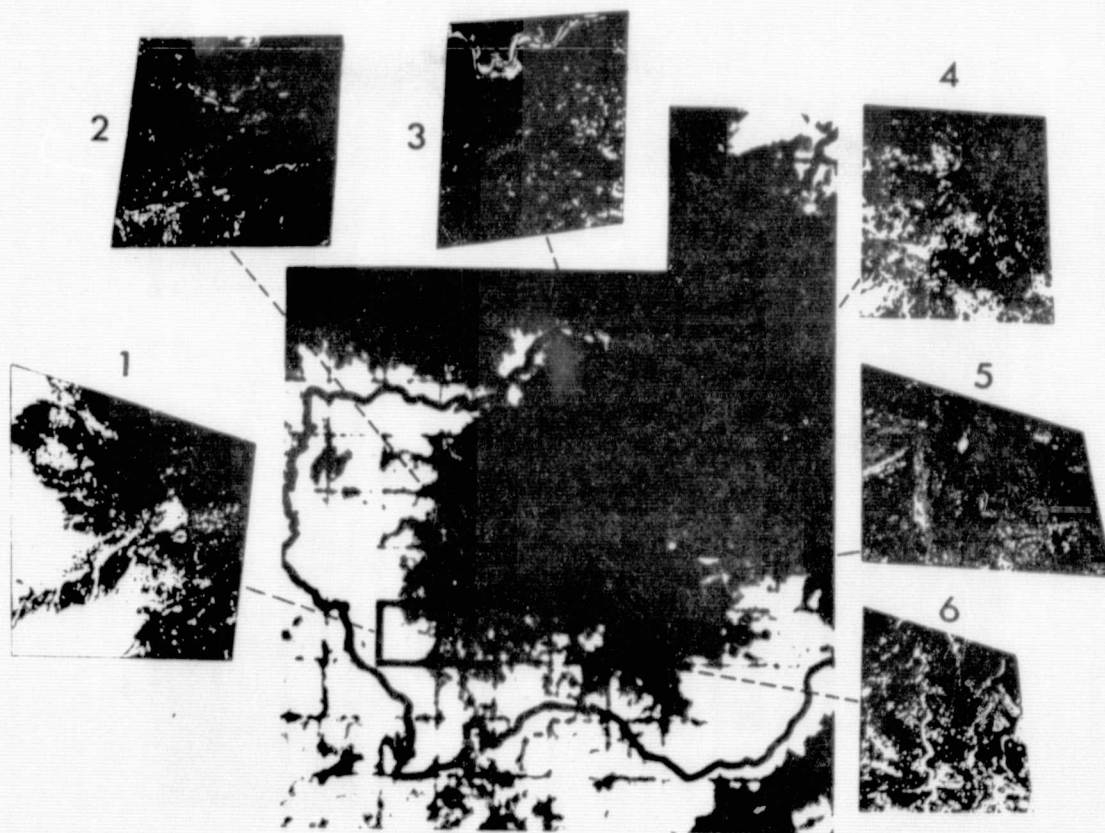


Figure 2.2.5b. The western half of the Spanish Creek Watershed showing the appearance of selected image sample units on LANDSAT-1 color composite imagery as opposed to their appearance on low altitude aerial photography. The image sample units equal 400 acres each (2000 metres on a side). Image sample units 2,3, and 5 show, snow cover class 2 area's, image sample unit 4 shows a snow cover class 3 area, and image sample units 1 and 6 show snow cover class 4 areas.

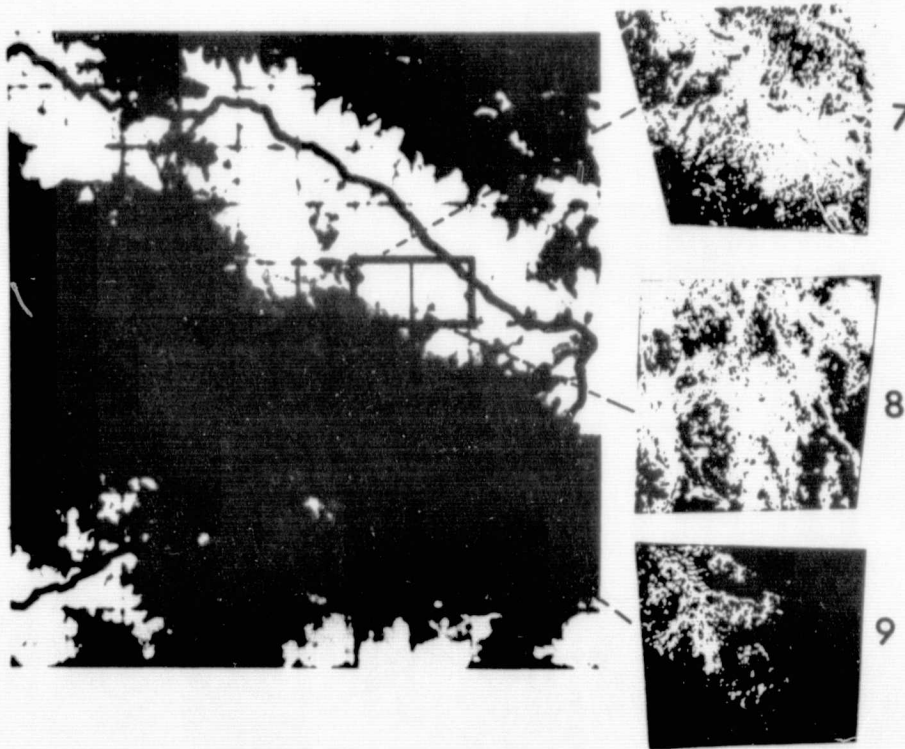


Figure 2.2.6b. The eastern half of the Spanish Creek Watershed showing the appearance of selected image sample units on LANDSAT-1 color composite imagery as opposed to their appearance on low altitude aerial photography. The image sample unit 9 shows a snow cover class 3 area, and image sample units 7 and 8 show snow cover class 5 areas.

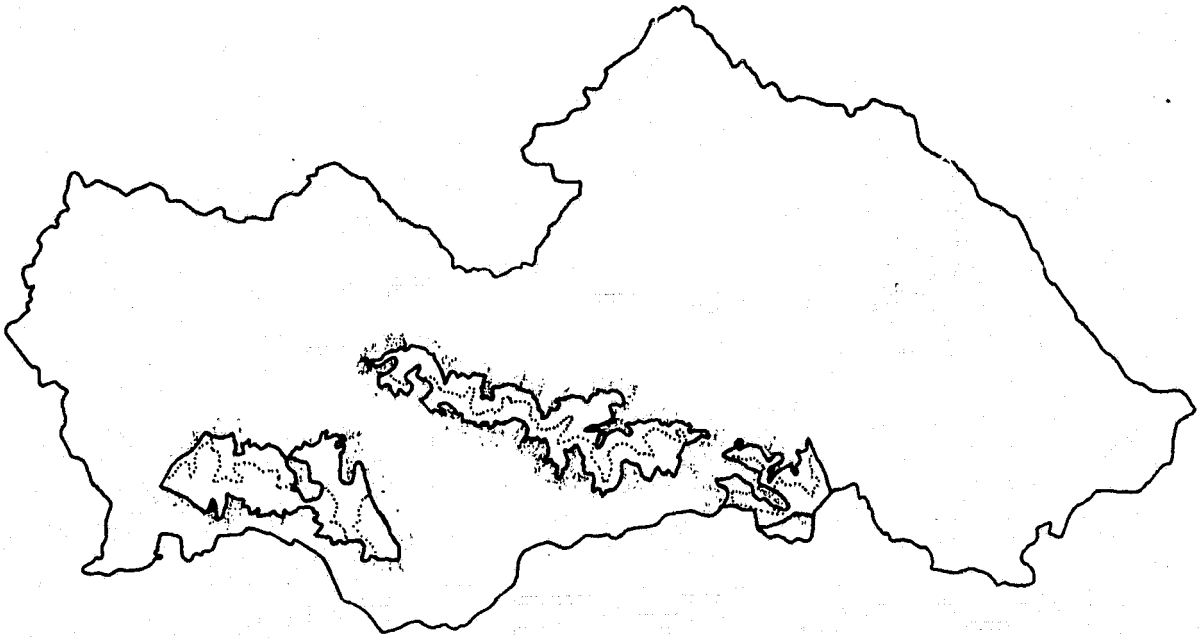


Figure 2.2.7b Outline of the Spanish Creek Watershed showing the high density mountain mixed conifer, northern aspect, 4000-5000 foot environmental unit. Dotted lines indicate the 4500 foot contour.

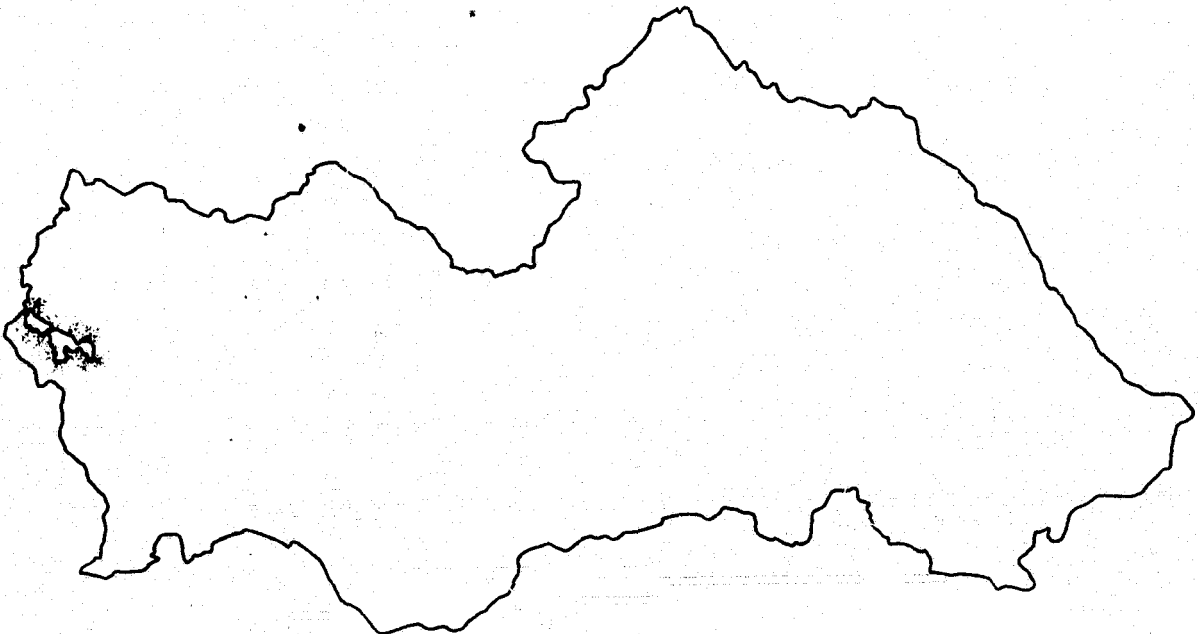


Figure 2.2.8b. Outline of the Spanish Creek Watershed showing the impervious wildland bare ground eastern aspect, 5000-6000 foot environmental unit. Actual elevations within this particular environmental unit range from 5500 to 6000 feet.

Environmental Units, Spanish Creek Watershed

TABLE 2.2.9b

<u>No.</u>	<u>Vegetation/Terrain</u>	<u>Elevation</u>	<u>Aspect</u>
1	Red Fir, High Density	5000-6000'	SW
2		6000-7000'	SW
3		5000-6000'	E
4		6000-7000'	E
5	Red Fir, Low Density	5000-6000'	E
6		6000-7000'	E
7		6000-7000'	SE
8	Mountain Mixed Conifer, High Density	3000-4000'	N
9		4000-5000'	N
10		5000-6000'	N
11		6000-7000'	N
12		4000-5000'	NE
13		3000-4000'	E
14		4000-5000'	E
15		5000-6000'	E
16		3000-4000'	S
17		4000-5000'	S
18		5000-6000'	S
19		3000-4000'	SW
20		4000-5000'	SW
21		5000-6000'	SW
22		6000-7000'	SW
23		7000-8000'	SW
24		3000-4000'	W
25	Mountain Mixed Conifer, High Density	4000-5000'	W
26		5000-6000'	W
27		6000-7000'	W

Environmental Units, Spanish Creek Watershed

TABLE 2.2.9b(cont)

<u>No.</u>	<u>Vegetation/Terrain</u>	<u>Elevation</u>	<u>Aspect</u>
28		3000-4000'	L
29	Mountain Mixed Conifer, Low Density	3000-4000'	N
30		4000-5000'	N
31		5000-6000	N
32		3000-4000'	NE
33		4000-5000'	NE
34		3000-4000'	E
35		4000-5000'	E
36		5000-6000'	E
37		3000-4000'	S
38		4000-5000'	S
39		5000-6000'	S
40		3000-4000'	SW
41		4000-5000'	SW
42		5000-6000'	SW
43		6000-7000'	SW
44		3000-4000'	W
45		4000-5000'	W
46		5000-6000'	W
47	Eastside Mixed Conifer, High Density	4000-5000'	SW
48		5000-6000'	SW
49		6000-7000'	SW
50	Eastside Mixed Conifer, Low Density	6000-7000'	SW
51		7000-8000'	SW
52	Water	3000-4000'	L
53		5000-6000'	L
54	Grassland	3000-4000'	SW

Environmental Units, Spanish Creek Watershed

TABLE 2.2.9b (cont)

<u>No.</u>	<u>Vegetation/Terrain</u>	<u>Elevation</u>	<u>Aspect</u>
55		3000-4000'	L
56	Xerix Hardwoods, High Density	3000-4000'	N
57		4000-5000'	N
58		5000-6000'	N
59		4000-5000'	SW
60		5000-6000'	SW
61	Xeric Hardwoods, Low Density	3000-4000'	SW
62		4000-5000'	SW
63		5000-6000'	SW
64		6000-7000'	SW
65		3000-4000'	L
66	Mesic Hardwoods, High Density	4000-5000'	L
67		5000-6000'	N
68		6000-7000'	N
69		4000-5000'	SW
70		7000-8000'	SW
71	Brush, High Density	4000-5000'	N
72		5000-6000'	N
73		6000-7000'	N
74		4000-5000'	E
75	Brush, High Density	5000-6000'	E
76		6000-7000'	E
77		3000-4000'	S
78		3000-4000'	SW
79		4000-5000'	SW
80		5000-6000'	SW

Environmental Units, Spanish Creek Watershed

TABLE 2.2.9b (cont)

<u>No.</u>	<u>Vegetation/Terrain</u>	<u>Elevation</u>	<u>Aspect</u>
81		6000-7000 '	SW
82		7000-8000 '	SW
83		4000-5000 '	W
84		5000-6000 '	W
85		6000-7000 '	W
86	Brush, Low Density	6000-7000 '	N
87		5000-6000 '	E
88		3000-4000 '	S
89		4000-5000 '	S
90		5000-6000 '	S
91		4000-5000 '	SW
92		5000-6000 '	SW
93		6000-7000 '	SW
94		7000-8000 '	SW
95		5000-6000 '	W
96		6000-7000 '	W
97		3000-4000 '	L
98	Serpentinic Vegetation Association	3000-4000 '	N
99		4000-5000 '	N
100	Serpentinic Vegetation Association	3000-4000 '	W
101		4000-5000 '	W
102		5000-6000 '	W
103		6000-7000 '	W
104	Bare Soil	4000-5000 '	N
105		4000-5000 '	S
106		6000-7000 '	SW
107		7000-8000 '	SW
108	Exposed Bedrock	5000-6000 '	E

Environmental Units, Spanish Creek Watershed

TABLE 2.2.9b (cont)

<u>No.</u>	<u>Vegetation/Terrain</u>	<u>Elevation</u>	<u>Aspect</u>
109		6000-7000'	E
110		3000-4000'	L
111	Urban	3000-4000'	N
112		3000-4000'	L
113	Mesic Rangeland	3000-4000'	N
114		4000-5000'	SW
115		3000-4000'	L

of key ground station points associated with the image sample units. Information in this form provides an input, based on snow depletion rates, for use in a remote sensing-aided prediction of basin-wide snow water content estimation (Thomas, 1974).

Of all the parameters described that could be useful in such a library, probably the most difficult to incorporate is that of the environmental unit. Preliminary studies using the Spanish Creek Watershed (a sub-watershed of the Feather River Watershed) as a representative example have yielded 115 different combinations based on 18 vegetation/terrain classes (adapted from Krumpke, 1969), 7 aspect classes, and 5 elevation classes. Table 2.2.9b lists all of these combinations; Figures 2.28b and 2.2.9b illustrate two of these unique combinations in respect to the Spanish Creek Watershed. All of the environmental units defined can be produced in transparent acetate from corrected to overlay directly on LANDSAT images thus aiding the image analyst in his appraisal of the snow conditions within a given image sample unit.

For training purposes, the specific image sample units (as imaged on LANDSAT) that were chosen for inclusion in the snow cover condition library would have associated overlays. These overlays would define the relationships between the environmental units and snowpack appearance in specific ISU's. Additionally the environmental units could also be related to the ISU's on the cloud free summer date. Consequently the image analyst would be able to judge not only the appearance of snow in specific environmental units but also the appearance of the snow-free summer landscape. The combination of the two landscapes allows the image analyst to make better decisions on areal extent of snow using the stereoscope technique described previously.

The true benefit of compiling a library of snow cover conditions lies in the fact that, upon completion, training and testing of the image analyst could be conducted from the data contained from within the library. Relatively frequent acquisition of a sample of supporting aerial photography is therefore unnecessary. Table 2.2.9b shows a possible format for the library. This layout would allow the analyst to choose a date from a previous year which most closely matches the appearance and other criteria of the current snowpack condition being analyzed for snow areal extent.

Determination of whether one year's conditions match another's is based upon the fact that the snowpack builds up and depletes in a unique fashion (Garstka, Love, Goodell, and Bertle, 1958). By comparing the visual appearance, the date, and the previous winter storm data between specific ISU's; in the library and of the current date of imagery being analyzed, the individuals conducting the investigation can make the decision as to which date or previous imagery contained in the library best approximates the current snowpack situation.

Once a date of imagery which satisfies all the specified conditions is found, the image analyst may be trained. The training procedure essentially

TABLE 2.2.10b

EXAMPLE FORMAT FOR THE SNOW COVER APPEARANCE LIBRARY

I.S.U.	Snow Cover Class	Winter Low Altitude Photo Appearance	Winter LANDSAT Image Appearance	Date	Summer LANDSAT Image Appearance	Environmental Unit Overlay	Previous Winter Storm Data			Snow Water Content of Key Ground Station Points Associated with the Winter LANDSAT Image Appearance Types
							Date	Magnitude	Temperature	

allows the analyst to look at a representative set of ISU's which cover a wide variety of snowpack and environmental conditions and establish the snow cover classes determined previously. By reviewing the information contained in the library for these ISU's the analyst can also form some ideas on why the snowpack appears as it does. This procedure will help him form more confident and accurate opinions of snowpack cover class during the actual interpretation of the imagery. The testing procedure, discussed in an earlier section, would derive its "ground truth" from the evaluation of the snowcover class of specific ISU's as contained in the library. These values would be compared to the analyst's interpretation values and the appropriate statistical tests could then be applied.

2.240b Conclusions and Recommendations for Future Research

Although the nature of the data acquired by the LANDSAT-1 satellite lends itself directly to automatic computer analysis for areal extent of snow estimation, research in manual techniques can be justified by comparing the two methods of operation to one another on a cost-effective basis. Research is currently being carried out on both phases of snow areal extent estimation procedures, analyses will be conducted testing both automatic, manual and a combination of automatic and manual techniques on a cost-effective basis.

Besides being justifiable on this basis, continued research utilizing manual techniques can provide analyses in certain circumstances where computer classification has not been sufficiently refined. Scattered cloud cover over snowpack may present some difficulty to present computer analysis; however the human has little difficulty distinguishing the two as they appear on LANDSAT-1 images.

Both the type I and the type II inventory methods for areal extent of snow estimation show great promise for providing fast, economical, and accurate inventories of snowpack areal extent. As each is refined, such as by optimizing image sample unit sizes and snow cover class width, estimates as to the true areal extent of snow should become more precise and should be made with greater confidence, all other factors being equal.

Future work will utilize a computer program, code named MAPIT, which has been developed under this NASA grant to coordinate and in part, analyze the various data sets to be used during this research. This program resident at the Lawrence Berkeley Radiation Laboratory, will recognize a number of data types from a variety of sources. These types include: spatial information such as stratification schemes, aspect outlines, elevation delineation, and vegetation boundaries; images or radiometry (multi-band) maps in either NASA format or reformatted Remote Sensing Research Program (RSRP) format; control point information for registering outlines on images;

classification maps, or CALSCAN output (a RSRP computer program which classifies imagery according to the information desired). A variety of intermediate results in map form will also be generated and organized by MAPIT. These maps and the various summaries and displays of these maps will serve as checkpoints during the project.

Mapit's functions with regard to the areal extent of snow estimation procedure are more involved than simple data storage and retrieval. The program has the capability of transforming different data types into a common form for comparison purposes. In regard to the areal extent of snow estimation procedure this would involve the input of spatial information in the form of elevation, aspect, and vegetation outlines to give the specific environmental units as discussed in a previous section. Under a user's supervision, the program can generate displays, summaries, or new maps in formats compatible with a wide range of display or storage devices. Significant operations will be stored in and fetched from MAPIT'S "content addressable data bank" for this project.

Appendix I for Section 2.2b

Ratio Estimator Statistic

Y_R = The true areal extent of snow

\hat{Y}_R = The estimate of the true areal extent of snow
 $= X\hat{R}$

where: $X = \sum_{j=1}^N X_j$

Given that: X_j = LANDSAT-1 interpretation estimate of the number
of acres of snow by snow cover class

= (Snow cover class midpoint)(400 hectares)

j = Index for all LANDSAT-1 image sample units

N = Maximum LANDSAT-1 image sample unit index number

Where: $R = \frac{Y}{X}$ = The population ratio estimator

Given that: $Y = \sum_{i=1}^n y_i$

$X = \sum_{i=1}^n x_i$

n = Total number of LANDSAT-1 image sample units
sampled with large scale aerial photography

i = sample index

y_i = Large scale photo estimates of the acres of snow
for sample LANDSAT-1 image sample unit i

= (Snow cover class midpoint)(400 hectares)

x = LANDSAT-1 interpreter estimate of the number of
acres of snow for sample image sample unit i
= (Snow cover class midpoint)(400 hectares)

$$V(\hat{Y}_R) = \text{Sample variance} = \frac{N(N-n)}{n(n-1)} \left[\sum_{i=1}^n y_i^2 + \hat{R}^2 \sum_{i=1}^n x_i^2 - 2\hat{R} \sum_{i=1}^n x_i y_i \right]$$

Confidence interval around Y_R : Example for 95% level of confidence

As expressed in acreage limits:

$$\text{Probability} \left[\hat{Y}_R - t_{n-1, .025} \sqrt{V(\hat{Y}_R)} \leq Y_R \leq \hat{Y}_R + t_{n-1, .025} \sqrt{V(Y_R)} \right] = .95$$

As expressed as allowable error (AE):

$$AE = \frac{t_{n-1, .025} \sqrt{V(\hat{Y}_R)}}{\hat{Y}_R}$$

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2.300b SEMI-AUTOMATIC ANALYSIS OF LANDSAT DIGITAL DATA FOR SNOW AREAL EXTENT ESTIMATION

2.310b Approach and Data Set

In order to quantify additional improvements in performance, cost-efficiency, and available information to be gained by computer analysis of image sample units (ISU's) relative to manual methods, a semi-automatic analysis of LANDSAT digital data for snow areal extent estimation is being performed. This analysis will also provide the LANDSAT digital base for eventual first sample stage PSU estimates of snow water content and evapotranspiration.

The manual procedure to be used for comparison will be that described in section 2.211b. Thus computer classified image sample unit results using a parametric classifier will be double sampled in the same manner as for the human interpreter approach. A comparison will then be made of the relative precision, cost and timeliness of the two methods.

Snow season dates selected for analysis include April 4, May 10, and May 28, 1973. These are the same dates analyzed in the manual technique and were selected so as to allow the most direct comparison between methods possible. In addition, one cloud free summer LANDSAT overpass has been selected, that of August 13, 1972, which will provide a clear recording of vegetation/terrain relationships. This summer date will be used to generate spectral mean and variance statistics for the specific vegetation/terrain parameters found to be necessary for semi-automatic snow areal extent estimation. The manual technique utilized a summer date for similar purposes.

A subunit of the Feather River Basin, the Spanish Creek Watershed, has been selected as the location for initial evaluation of the computer snow classification technique. This smaller watershed provides a good representation of the vegetation/terrain conditions of the larger basin. It therefore provides an opportunity for more time and cost-efficient intensive analysis of the semi-automatic approach. Manual areal extent estimates by image sample unit have been summarized for the Spanish Creek Watershed for comparative purposes.

2.320b Procedure for Semi-Automatic Snow Areal Extent Estimation

LANDSAT frame digital data for dates of interest are divided into four quadrants. After those quadrants covering the specified basin are selected, the human-computer processing steps proceed as follows at the Remote Sensing Research Program.

The first step involves data reformatting for each of the quadrants selected on the LANDSAT raw digital tapes. The reformatting simply transforms the LANDSAT data into a form acceptable to the data processing system. Before the actual reformatting procedure begins, the tapes are checked for calibration with respect to the spectral information (in

the form of reflectance histograms) gathered by each of the six sensors which simultaneously acquire data in each band. Means of spectral response for each sensor histogram are compared. The sensors are readjusted if their means do not fall within one spectral level of all other sensor means for the same band.

After the applicable quadrants of the LANDSAT raw tapes on all dates have been reformatted and recalibrated, the adjacent quadrants on a given date are combined on one tape, this new tape being designated a test tape. The test tape is then used to form color enhancements of selected areas which are displayed on a video monitor. The area covered, the location of the area, the color balance, and informational content of the area displayed can all be controlled by the operator. A gridding system can be introduced to the video display to facilitate the precise location of control point features and training field locations for snow-environmental units of interest.

In order to accurately analyze the LANDSAT multigate information, the test tapes for given dates must be calibrated to each other in an x,y coordinate system. In other words, the digital information on each tape must be aligned so that all features on one tape overlay the same features on the next date. In this way information on a point-by-point basis may be compared for analysis purposes. This is done by selecting a given number of control points on each date that will be visible on all other dates. Then, using a least squares regression fit, the test tapes may be mathematically aligned with respect to each other.

Control points such as bends in river channels, points of lakes, and other conspicuous features are chosen so that they are visible on all dates. The selected points are displayed for each date on the video color monitor, using the grid command to allow accurate x and y location, and photographed using Polacolor Type 108 film. Use of this film type allows the establishment of a permanent record of the control point with respect to its own coordinate system. Thus the LANDSAT absolute coordinates of the points may be established and checked later.

Snow cover class vegetation/terrain environmental units defined in the manual technique are located on the digital data video presentation and photographed in a manner similar to control points. The snow-environmental units provide training statistics for automatic classification of snow presence on a pixel by pixel basis. This classification will proceed on a multigate LANDSAT data set consisting of a summer date and the snow season date of interest. It is possible that two summer dates may be used to increase accuracy of environmental unit definition.

For cost-efficient manipulation of LANDSAT data and for watershed specific summary of snow-environmental unit information, a watershed mask is incorporated into the digital data base. This mask represents the watershed boundary in terms of the LANDSAT coordinate system. Processing of pixel information outside the boundary can then be optionally ignored by use of the mask.

After computer classification within the outlined watershed the pixels are grouped automatically according to user specifications into image sample units. These sample units may then be subsampled with medium altitude photography as in the case of the manual technique. Resulting ratio or regression estimates of snow areal extent for the basin or sub-basin of interest may then be formulated.

Resulting computer classified image sample unit data may also be combined for several dates, as described in Chapter 6, to estimate snow water content. Image sample units may then be subsampled by ground measurements to provide stratified basin estimates of snow water content.

The computer classified output will in addition be used to form PSU's to allow first stage estimates of water loss as described in section 2.110b. These results can be used in the multistage, multi-phase sampling design discussed there.

2.400b IMPERVIOUS SURFACE-PARAMETER ESTIMATION

2.410b Justification and Definitions

An important aspect of watershed management is the estimation of the magnitude and timing of runoff after a basin has experienced a hydrometeor (precipitation input). One parameter that has a significant impact on this estimation is the amount of impervious surface area within the watershed. An impervious surface can be defined as an area which exhibits almost instantaneous runoff upon the receipt of precipitation in the form of water. If the surface is adjacent to an established water channel, the runoff is immediately conducted to the channel system and is, therefore, delivered to the appropriate gauging station more quickly than water falling on pervious areas which act as water runoff delay mechanisms. Precipitation falling on pervious (permeable) areas must percolate through the soil and satisfy given soil moisture requirements before runoff can be released to the channel system. Pervious surfaces, in that they delay delivery of precipitation to the channel system, tend to smooth out and lower maximum flow peaks on the hydrograph of a channel system. Impervious surfaces, in contrast, tend to sharpen and amplify the maximum water flow peaks. Thus in trying to assess the ability of storage facilities to accept the runoff from a given amount of precipitation within a given period of time, the amount of impervious surface adjacent to stream channels within a basin is an important parameter to consider and evaluate.

There are two general types of impervious surfaces that must be considered--permanently impervious surfaces and temporarily impervious surfaces. Permanently impervious surfaces experience direct runoff almost immediately upon the beginning of the receipt of precipitation. Such surfaces include water surfaces such as lakes, streams, bogs, bare rock surfaces which do not have any significant surficial soil accumulations, paved areas such as roads, and compacted soil areas.

Temporarily impervious surfaces do not experience direct runoff until a given moisture storage capacity has been exceeded. After this point, any additional input of water flows away as direct runoff. Such surfaces include any saturated soils (those which are incapable of absorbing any further amounts of water within their structure) as found in wet meadow and riparian vegetation areas, or areas where the precipitation rate exceeds the infiltration rate for a particular

soil. In the latter case, the excess which flows away as a direct runoff is the difference between the precipitation rate and the infiltration rate.

Area estimates for watershed impervious surfaces and temporarily impervious surfaces are two drivers in the California Federal-State River Forecasting Center (RFC) Sacramento hydrologic model. The RFC model flood peak magnitude and timing predictions may be particularly sensitive to these two parameters during short time intervals of high watershed precipitation intensity. Presently these parameters are generally set through analysis procedures, such as stream hydrograph analysis. Thus a cost-effective means of utilizing remote sensing techniques to accurately estimate the watershed area of impervious and temporarily impervious surfaces may provide an especially valuable check on current estimates of these parameters.

2.420b Sample Design

The approach to estimation of permanently impervious and temporarily impervious surface areas (ISA's) utilizing remote sensing data is presently proposed in terms of two procedures. The first procedure (sample design I) uses high altitude, 1:120,000 scale photography to produce these estimates. Effective areas¹ on overlapping photographs of this kind for the watershed of interest are stratified into units of relative impervious surface proportion homogeneity. Within these strata, sample points are examined for presence of impervious surfaces. A subset of these are sampled again (i.e. double-sampled) on more resolved information to calibrate the high flight estimate.

A sampling technique as opposed to a delineation technique for ISA estimation on high altitude photography is proposed due to the following reason. Contiguous areas of impervious surfaces can be relatively small when imaged on high altitude, 1:120,000 scale photography. While the original scale of the photography is sufficient for identification, it is not for annotation. Thus, to map the boundaries of these areas so that their acreage can be determined is a difficult and time consuming job. Consequently the suggested point sampling technique has been proposed to generate a percentage estimate of the impervious surface for the watershed of interest.

The second estimation procedure (sample design II) involves the multistage, multiphase sampling design described in section 2.110b for water loss estimation. In this scheme, estimates of permanently and temporarily impervious surface areas can be made from automatically classified LANDSAT digital data. These estimates can be grouped by primary sampling units. Subsampling of these sampling units as illustrated in Figure 2.10b, should allow refined estimates of ISA.

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1. By definition, for any aerial photograph that is one of an overlapping series, the "effective area" is that central part of the photograph delineated by the bisectors of overlaps with the adjacent photographs.

2.421b Stratification Strategy

The first step in either procedure is to stratify the watershed into relatively homogeneous geologic-geomorphic units. This can be quickly done by transferring the boundaries of the units from geologic maps of the area to the high altitude photography in the case of sample design I. These boundaries may be digitized for automatic overlay on ERTS digital data for sample design II. It may be desirable to consolidate some of the geologic units if they respond similarly to processes of weathering and erosion. The reason for stratifying on a geological-geomorphological basis is that different lithologic (rock) types give rise to different proportions of impervious surfaces and thus to different variability values for impervious surface area estimates. By sampling strata with relatively similar impervious surface area proportions, the variance and therefore precision of the area estimate can be controlled.

The phenomenon of different impervious surface area proportions among geologic-geomorphic strata is due to the fact that different rock types respond differently to weathering and erosional processes and thus develop different characteristic terrain types. These terrain categories in turn may or may not foster conditions which would tend to develop one of the kinds of impervious surfaces. For example serpentinitic areas tend to develop soils of low permeability due to their mineralogy. These areas support a sparse vegetation cover in a rock matrix thus allowing their identification on imagery. Also massive granitic areas weather along rectilinear joints and fractures such that these terrains often display numerous domal features. Along the joints and fractures which occupy the low areas between the domal highs, drainage rates may be low enough to allow development of saturated soil conditions. Such effectively water impervious saturated areas can be relatively permanent for many months during the spring and summer runoff periods. Glaciated areas (especially within granitic terrains) may have numerous small tarn or cirque lakes, as well as a high proportion of other water-impervious surfaces such as exposed bare rock. Thus the proportion of an area occupied by impervious surfaces is somewhat dependent on its lithologic type and on the landscape that develops within that type. By stratifying on this basis, the variance of the point sample is lowered and so the precision of the area estimate is improved.

The geologic-geomorphic units that are pertinent within the Spanish Creek sub-basin (Bucks Lake-American Valley Area) are:

- Granitic terrain
- Metamorphic terrain (includes both Paleozoic and Mesozoic metasedimentaries and metavolcanics)
- Serpentinitic terrain
- Tertiary volcanics (Eocene gravels)
- Quaternary alluvium
- Pleistocene glacial depositions
- Water surfaces

Water surfaces (lakes) smaller than 150 acres should be excluded from individual strata in order to control estimate variance. The area of these larger water bodies is put into a separate "water-only" watershed stratum defined as a 100 percent impervious surface. For efficient ISA estimation on high flight imagery, the minimum geologic-geomorphic area to be delineated, other than water bodies, should be no smaller than one square mile.

2.422b Sampling Method for High Flight Imagery

After the stratification system has been developed for an area, the point sampling grid can then be developed. The density of the grid in a given stratum is set so as to give a watershed or sub-basin estimate of impervious surfaces adjacent to stream channels with a given precision (Cochran 1963 and Thomas 1974). Resulting grids are then overlaid randomly on the effective area of the photography for each stratum. The area falling beneath each grid point is then identified as to whether it is:

water surface
bare rock surface
paved road
dirt road
compacted soil area

} permanently impervious surfaces

or

riparian hardwood area
wet meadow area
dry meadow area

} temporarily impervious surfaces or
potentially impervious surfaces

or

other - (pervious) surfaces

and whether it is adjacent to a channel system or not.

The permanently impervious surface conditions listed above are easily identified on 1:120,000 scale color infrared photography. As they are all non-vegetated conditions, the surface below a grid point can be identified relatively easily unless it is in shadow. The temporarily impervious surfaces usually have some form of vegetative covering whether it be trees and brush or grasses and forbs. Many riparian hardwood areas occur as lineal features along small channels. These riparian stringers appear as bright red on color infrared photography due to the relatively high near-infrared reflectance of such vegetation. There is possible confusion of riparian hardwood types

with dry site hardwood types since the dry site hardwoods also have a high infrared reflectance. However, by taking into account the topographic location of the hardwood vegetation, one can infer within certain probabilities whether the site is a riparian site or a dry site.

The wetness or dryness of a meadow area can be evaluated on the color infrared photography by the amount of near-infrared reflectance returned. The bright red color of moist meadows can be observed to decrease in some of the meadows as the summer season progresses and the meadows dry out. As the meadow's vegetation dries, the near-infrared reflectance decreases.

Since there is a good amount of snow that falls within the area during the winter months, the residual snowpack often prevents impervious surface photo interpretation well into June. Thus for evaluating impervious surface areas, it is necessary to obtain photography flown in the summer months (mid-June through late September). On imagery evaluated to date, September color-infrared photography appears to offer the best contrast between riparian hardwood vegetation and the surrounding conifers. This could possibly be due to a real decrease in the near-infrared reflectance of conifers relative to earlier values in the summer. Such reflectance decreases may result from partial collapse of the normally turgid and highly infrared-reflective spongy leaf mesophyll, caused by lower available soil moisture late in the summer season. However, a definitive statement about the higher contrast of the September imagery cannot be made due to photographic processing variability among different sets of color infrared photography.

After interpretation is completed for grid points in all strata for the watershed areas of interest, a sample of grid points in each stratum is examined on large scale photography or by ground visitation. For these double sampled points the actual presence or absence of an impervious surface area is determined from the examination of the large scale imagery or from ground data. These "ground truthed" points then allow a calibration of the ISA estimate made on high flight data according to area estimation formulas described in Cochran (1963) and Thomas (1974). ISA estimates are summarized by impervious and temporarily impervious surface types adjacent to stream channels.

2.423b Sampling Method Utilizing LANDSAT Data

Impervious surface area estimation performed in accordance with the multistage, multiphase sampling design for water loss estimation given in Figure 2.1.1b may proceed after geologic-geomorphic stratification is completed. Computer classification training statistics are generated for the impervious and pervious surfaces given in section 2.422b. These statistics should be specific to a clear, late summer LANDSAT overpass date, or a combination of several clear, snow-free dates. Computer training

fields for these surfaces are most efficiently located on video displays of LANDSAT scenes by manually referring to known locations on highlight imagery.

After automatic classification of LANDSAT digital data has been accomplished, pixels are grouped into primary sampling units (PSU's) following the discussion of section 2.110b. These PSU's are then subsampled with photo and ground secondary sampling units (SSU's) as discussed there. In fact, these SSU's may be the same ones used for snow water content or evapotranspiration estimation. Estimates of impervious surface area would then be made for each geologic-geomorphic stratum according to the PSU's and associated SSU's falling in each. Strata estimates of ISA would be grouped to give watershed or sub-watershed estimates of both impervious and temporarily impervious surface areas. Weighting coefficients to quantify the distance of impervious surface areas in SSU's from stream channels will have to be developed in order to make the final ISU estimates truly consistent with RFC hydrologic model impervious and temporarily impervious surface input requirements.

2.430b Future Work for Impervious Surface Estimation

Tests and further development of the proposed impervious surface estimation procedures should be conducted coincident with the development of the water loss and hydrologic parameter estimation procedures described elsewhere in this chapter. Further work regarding impervious surface evaluation and estimation will necessitate additional field work next summer to better define certain vegetation type-site location associations.

2.500b DEVELOPMENT OF A METHODOLOGY FOR EVAPOTRANSPIRATION ESTIMATION

2.510b Introduction

2.511b Justification

Water vapor is the principal participant in the many energy exchanges taking place in the atmosphere. These energy exchanges are responsible for the weather phenomena which serve as important links connecting the various phases of the hydrological cycle.

Quantification of the water flux mechanisms, viz. evaporation and evapotranspiration (which includes active plant water loss), is of importance in many scientific fields. They form one of the main components of the water budget, knowledge of which is indispensable for the solution of numerous water management problems. Reliable evaporation data are required for planning, designing and operating reservoirs, ponds, shipping canals, and irrigation and drainage systems. Evapotranspiration is especially important in arid zones where water must be used in the most efficient way possible. In addition, knowledge of the water requirement of crops depends partly on an accurate determination of the loss of water by evapotranspiration from cultivated fields.

Evapotranspiration, utilized here to represent both the evaporation and evapotranspiration processes, is the major water loss mechanism for watersheds throughout the world. Wherever there is vegetation or inorganic surfaces with water capable of being evaporated, water vapor loss from usable water yield will occur. At present only a thin network of transpiration measuring devices throughout the world exists (WMO, 1966). Significant difficulties are involved in extrapolating these data over watersheds with varying environmental conditions and in translating evaporation values to evapotranspiration values. No current operational evapotranspiration estimation system exists.

In view of the overriding importance of evapotranspiration to accurate basin water yield estimation and to other water consumptive use determinations described above, any cost-effective, precise evapotranspiration estimation system would be of significant utility to a water manager. Remote sensing techniques may provide the key to such a system's data requirements. Its timely, spatial, and relatively inexpensive nature when combined with other conventional meteorological data can potentially give rise to accurate, location-specific estimates of evapotranspiration.

Moreover, current water yield estimation procedures such as the California River Forecasting Center model can incorporate evapotranspiration estimates. It is therefore the purpose of this section to lay the foundation for a remote sensing-aided methodology for accurate and efficient watershed evapotranspiration estimation.

2.512b Background and General Definitions

The technology of water resources development, distribution, control, and management for the production of food and fiber has advanced significantly during the past quarter century. Similarly, the technology of measurements and determination of evaporative flux from land surfaces has made great strides since the studies of evaporation and energy balance by Bowen in the 1920's, and the aerodynamic studies of Thornthwaite and Holtzman in the 1930's.

Evaporation may be defined as the transfer of water vapor from a non-vegetative surface on the earth into the atmosphere. Evapotranspiration is the combined evaporation from all surfaces and the transpiration of plants. Except for the omission of a negligible amount of water used in the metabolic activities, evapotranspiration is the same as the "consumptive use" of the plants. The fact that the rate of evapotranspiration from a partially wet surface is greatly affected by the nature of the ground leads to the concept of potential evapotranspiration. Penman (1956) defines potential evapotranspiration as "the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short in water." Recently, Pruitt (1960) designated the term "potential maximum evapotranspiration" to describe

the situation when advected (horizontal movement of energy through the atmosphere surrounding the plant) energy is present. This removes any confusion on Penman's definition. Thus, one should not expect an empirical formula for potential evapotranspiration derived in a humid climate to be adequate for estimating the potential maximum evapotranspiration in an arid climate. The other term that must be defined is actual evapotranspiration. Actual evapotranspiration is the actual amount of water vapor transferred to the atmosphere. In addition to existing meteorological conditions, actual evapotranspiration also depends on the availability of water to meet the atmospheric demand and, in the case of vegetation, its ability to extract moisture from the soil.

Data on evapotranspiration are useful for estimating irrigation requirements, rainfall disposition, safe yield of ground water basins, water yields from mountain watersheds, and stream flow depletion in river basins.

In water resource investigations and water right controversies, engineers are frequently called upon to make, within a limited time, estimates of probable past, present and future consumptive use, irrigation requirements, and stream depletions in river basins. Currently determining actual or potential water losses from vegetation is difficult because of the complexity of the factors affecting evapotranspiration and the many problems involved in their measurement. Relatively accurate, timely, and cost-effective evapotranspiration estimates by a remote sensing-aided system could therefore provide needed and important data to engineers, land managers, and planners.

One objective of the current NASA Grant water supply study in the Feather River Watershed is to develop a general evapotranspiration estimation procedure utilizing remote sensing data. This method will be part of the larger water loss estimation procedure, described in section 2.100b, designed to produce more precise estimates of water yield. As such, data collection and processing will proceed in a cost efficiently integrated manner with other water loss variable estimation (e.g. snow water content determination).

Similar to the case of snow areal extent methodology development, it will be efficient for initial tests of the technique to be performed on the Spanish Creek Watershed. Later application of the estimation procedure to the entire Feather River Watershed is to be considered later.

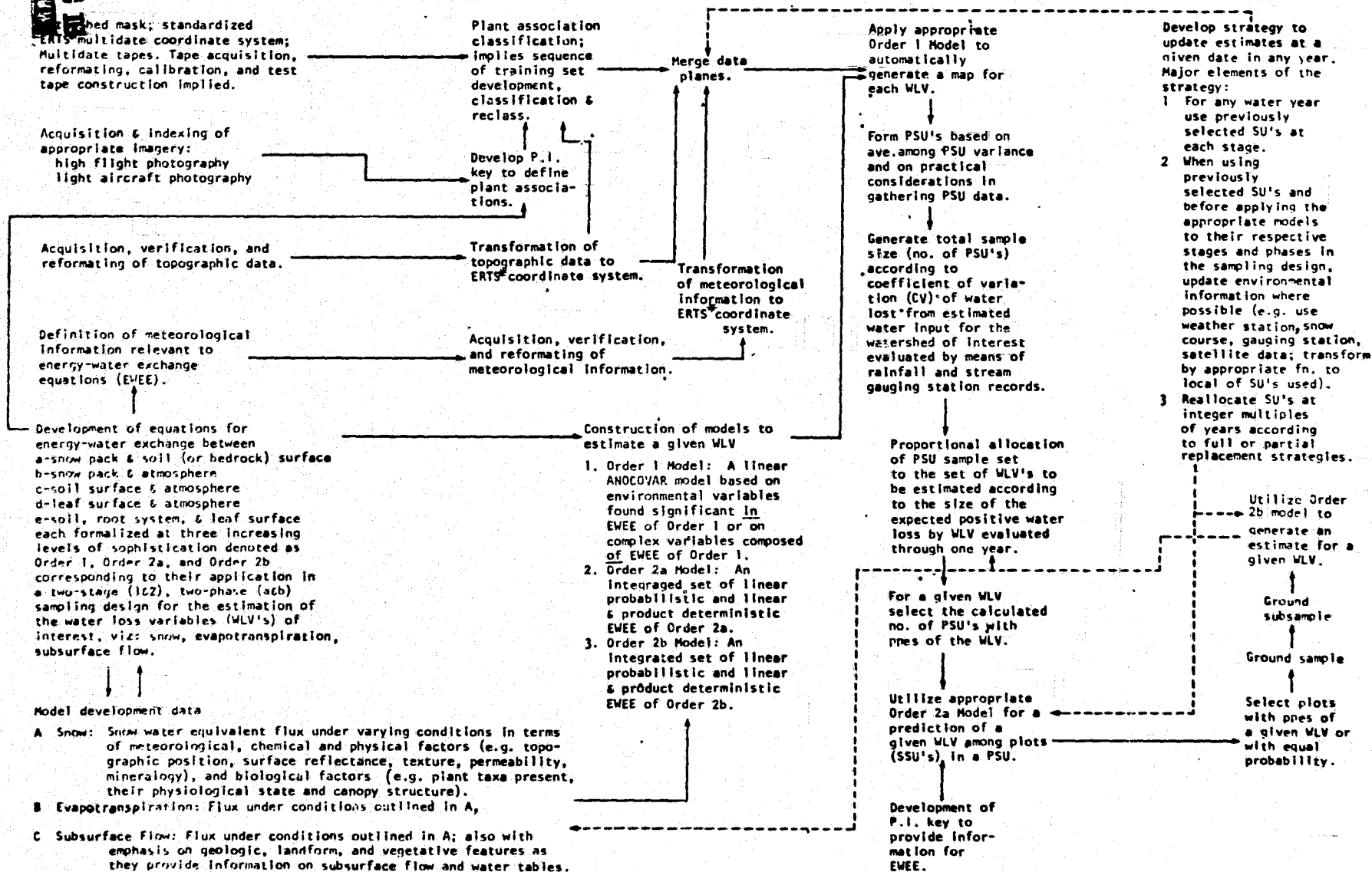
2.520b General Approach

2.521b Basic Sample Design and Corresponding Levels of Evapotranspiration Model Sophistication

A multistage, multiphase sample design will be utilized to estimate watershed evapotranspiration water losses. The general discussion of this approach was given in section 2.100b. Figure 2.5.1b repeats the outline of the discussion given there.

Figure 2.5.1b

Hydrologic Modelling: Quantification of Time Specific Water Runoff Loss to Snow, Evapotranspiration, and Subsurface Flow



Basically there are three increasingly resolved levels of information each of which is sampled. The first level is composed of satellite and topographic data. Vegetation, terrain, and meteorological types of information are defined for a convenient base resolution element, in this case the LANDSAT pixel. Based on the information associated with each base resolution element an estimate of evapotranspiration is made for that location. The appropriate evapotranspiration equation, defined as an Order 1 model in Figure 2.5.1b, must be able to perform adequately on this "least resolved" information available from the first data level. Adequate performance is defined as a generation of evapotranspiration estimates strongly correlated to actual ground measured or ground-based estimates of evapotranspiration.

After an estimate of evapotranspiration has been made for each basin resolution element, the resolution elements (here LANDSAT pixels) are grouped into primary sampling units (PSU's). The size and shape of these PSU's will be selected to minimize watershed evapotranspiration estimate variance within cost and practical subsampling constraints. A further aggregation of sampling units into various strata will then be performed. These strata may define sub-basin reporting units within the entire watershed and/or may define subunits of relatively homogeneous expected evapotranspiration rates designed to further reduce the estimate variance.

Based upon the variability among PSU's, a sample of these units will be selected within each stratum for further sampling. Selection may be with probability proportional to estimated size of evapotranspiration within given PSU's. The result in this case would be to direct the subsampling to areas of higher water loss. Alternatively, PSU selection could be with equal probability in the case where subsampled information would be used to estimate other water loss variables (e.g. snow water content) as well.

This subsampling will involve a series of large scale photographic plots, or secondary sampling units (SSU's), within each selected PSU. The photographic SSU data along with nearby snow course and ground station calibrated meteorological satellite data will provide the second level of information resolution.

At the SSU stage of the sampling design, much more specific information concerning local vegetation canopy, soil, and local climatic conditions will be available as opposed to that obtainable from information at level one. Thus evapotranspiration models employing more data types and more refined data will be used to generate evapotranspiration estimates for each PSU. These equations are denoted as Order 2a models in Figure 2.5.1b. Estimates at this stage will, however, be more expensive on a unit area basis than for first stage (PSU) evapotranspiration estimates.

A subsample of the SSU's within a given PSU will then be performed. This sample will be based on the within-PSU second stage sample unit variance

and selected precision constraints. Either probability proportional to "size of the evapotranspiration estimate" or equal probability selection will be utilized for this phase of the sampling design.

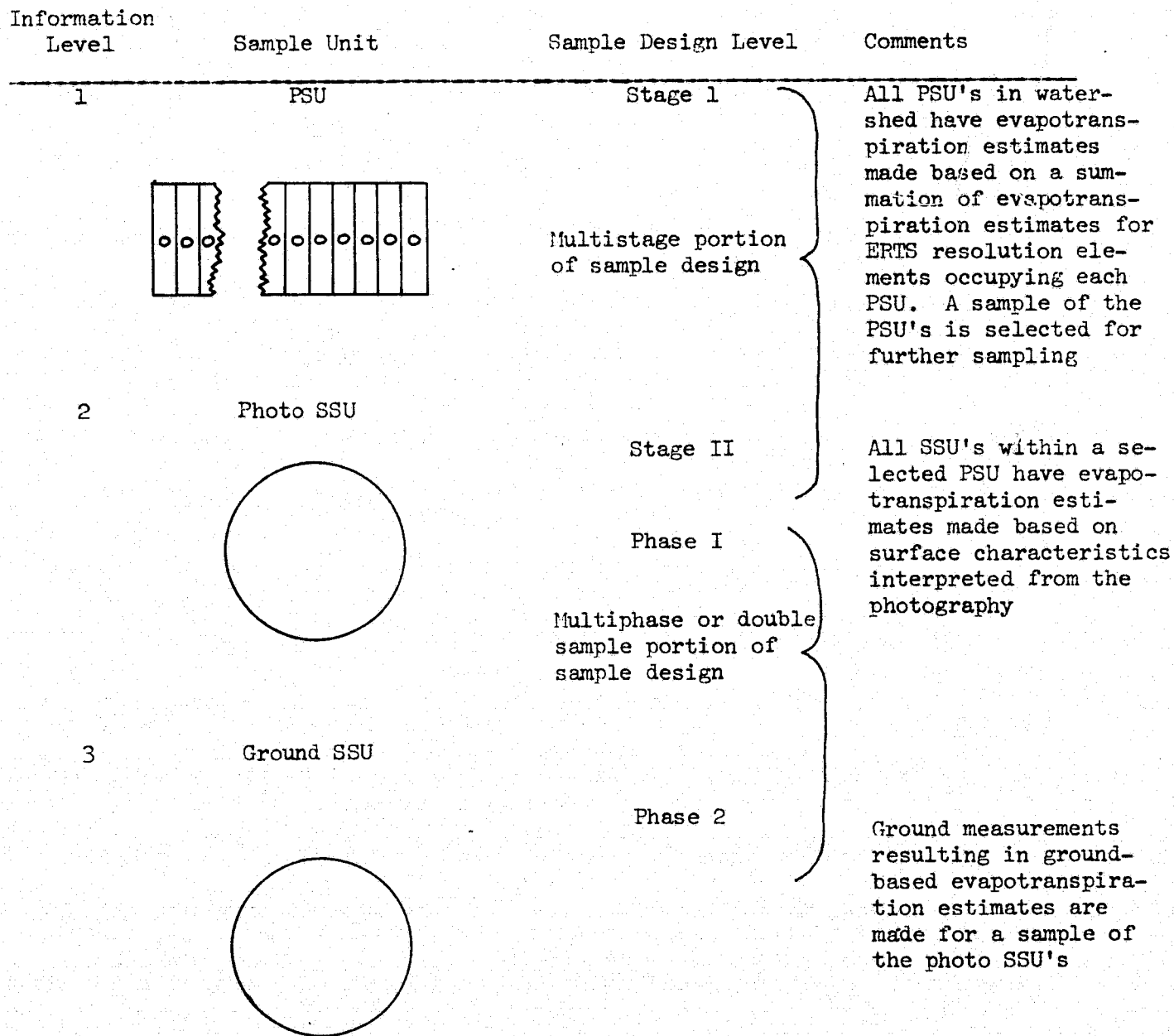
For each of the SSU's selected, detailed ground measurements will be made of vegetation canopy geometry, color, etc. as well as of soil and litter-organic debris conditions. The detailed data from this third level of information will then drive very sophisticated Order 2b evapotranspiration prediction models. Since estimates of evapotranspiration will be for the entire ground area of the SSU photo plot, this third stage unit (TSU) will actually comprise a double sample of the SSU's. Stated another way, the ground sample will comprise the second phase of a double sample in which the photo plots are considered the first phase. Data collection for information in level 3 will be the most expensive of all levels.

Figure 2.5.2b summarizes the sampling concepts and terminology in the preceding discussion. Note that the photo SSU is simultaneously the second sample stage and the first sample phase in this basic two stage, two phase sample design. Information levels 1, 2, and 3 specify the data plane at which a sampling operation takes place. Obtaining and processing information at increasingly higher information level numbers is exponentially more costly. Thus a smaller and smaller watershed area is sampled as the information level number increases.

The full watershed estimate of evapotranspiration can then be developed by first using the ground based evapotranspiration estimate to calibrate the SSU estimate based on photo data. The calibrated SSU estimates can then be expanded to the PSU stage by utilizing the SSU selection weights developed earlier. Finally, PSU evapotranspiration estimates can be expanded, each over the appropriate stratum, and then to the entire watershed by applying the PSU selection weights originally calculated. In this way, a cost-effective combination of an increasingly smaller sample of more precise and more expensive information levels can be utilized to give basin-wide watershed estimates.

Before moving further in this discussion, an additional advantage of the double sample between ground and photo SSU's should be noted. This advantage consists of the ability to calibrate vegetation and soil surface quantifications made on aerial photography with similar measurements made on the ground. Thus statistical relationships can be developed between ground and photo environment measurements. Importantly, these relationships may also be employed with SSU's where no ground data are available. Hence more accurate information is available from photo interpretation and thus more reliable evapotranspiration estimates are possible based on level 2 information. The same double sampling technique, sometimes used in combination with multistage sampling, can be employed with ground plots to efficiently describe very detailed canopy and soil characteristics. The information types and procedures for data collection utilized in the current year's NASA Grant water supply work

FIGURE 2.5.2b - EVAPOTRANSPIRATION SAMPLE DESIGN TERMINOLOGY



on the Feather River Watershed are given in Appendices III and IV for ground and SSU photo plots, respectively.

2.522b Other Models Important in the Evapotranspiration Estimation Process

In addition to (a) the information calibration models, (b) the model combining PSU and SSU estimates into watershed-wide evapotranspiration estimates, and (c) the models used to generate evapotranspiration estimates at the three levels of information, two other necessary modeling and estimation approaches should be described. The first of these is an equation set that is necessary to differentially segregate information obtained at resolution sizes spatially larger than the base resolution element sizes. An important example would be transforming data from a NOAA meteorological pixel, approximately 100 LANDSAT pixels square, into information specific to each of the corresponding LANDSAT pixels. This transformation process would involve two equation types. One would be a microclimatic function driven by topographic data, associated air flow characteristics, and LANDSAT results for vegetation/terrain types for individual pixels. This function would spatially define canopy-top meteorological values for each LANDSAT resolution element. The second equation would be a relationship, based on a double sampling technique, calibrating estimated meteorological data for LANDSAT pixels with corresponding data from ground meteorological stations occupying those resolution elements. Use of the calibration equation for LANDSAT pixels not having ground data would then be possible.

The second basic model not yet discussed involves a set of algorithms to distribute the canopy-top meteorological input derived as just described, vertically through the plant canopy. Thus a set of temperature and humidity profiles would be generated for the SSU photo and ground plot forest canopies. These micrometeorological profiles would allow the most efficient operation of the Order 2a and 2b evapotranspiration models. Each profile generating equation would be based on a number of plant geometry, soil, and topographic variables obtained from photo and field measurements.

2.523b Real-Time Evapotranspiration Estimates from the Sampling Framework

Depending on the use of water yield information, estimates of basin evapotranspiration may be needed on a daily, weekly, or monthly basis. In many cases, it would be extremely costly and perhaps physically impossible to reselect and reallocate sample units for each estimate reporting time. Hence a method allowing the use of previously selected sample units to generate evapotranspiration estimates must be employed.

The proposed procedure is as follows. The same photo SSU's, corresponding ground data, and associated photo-ground relationships are utilized repeatedly for a given period. The only changes in these data would be assumed to actual sample-obtained corrections for seasonal change in vegetation canopy or surface characteristics. Canopy-top meteorological data would be obtained by real-time spatial transformations of ground meteorological station, snow course-sensor, and meteorological satellite information. Meteorological profiling functions would then distribute the value of these parameters through the plant canopy. Real-time

evapotranspiration estimates for evapotranspiration models operating at information levels 2 and 3 would then be made. Similar meteorological updating of previously obtained LANDAT and topographic information would provide current evapotranspiration estimates from level 1 information. Evapotranspiration estimates for the entire watershed would then be obtained by the expansion process previously described. Primary and secondary sampling unit weights used in the "probability proportional to estimated size" multistage design would then be a function of the recalculated relative estimated evapotranspiration for each sampling unit.

Selected PSU's and SSU's would be replaced on a partial replacement basis at integer multiples of years. This would provide a cost-effective procedure to reallocate sample units and at the same time account for more situations and thus variability in watershed evapotranspiration.

2.524b Factors Affecting Evapotranspiration

Many factors operate singly or in combination to influence evapotranspiration. Their effects are not necessarily constant, but the factors may differ with locality, and water consumption may fluctuate from year to year. Some effects involve the human factor; others are related to the natural influences of the environment and to the growth characteristics of the plants.

The more important of the natural influences are climate, water supply, soils, and topography. The climatic factors that particularly affect consumptive use are temperature, solar radiation, precipitation, humidity, wind movement, length of growing season, latitude and sunlight. Most of these parameters then have the potential of being sensed remotely, and these data can be deduced from satellites equipped with suitable sensors.

Another factor which affects evapotranspiration is spatial variation. Factors determining spatial variation may be classified into energy supply and available moisture supply. Energy supply is governed by radiant energy, advected energy, stored heat, and wind turbulence. Available moisture supply is governed by areal rainfall distribution, runoff characteristics, and plant and soil characteristics.

The impact of the above factors on evapotranspiration is discussed in sections 2.530b and 2.540b and in detail in Appendices I and II. It is appropriate here, however, to summarize the general factors affecting evapotranspiration. Thus the factors to be included in the development of a complete formula for evapotranspiration should include consideration of the following:

1. Climatic variables
 - a. radiation
 - b. air temperature
 - c. humidity
 - d. wind movement
 - e. precipitation
 - (1) snow
 - (2) rain
 - (3) dew
 - (4) fog drip
 - f. evaporation
 - (1) land areas
 - (2) water surfaces
 - g. transpiration
2. Physical variables
 - a. latitude and longitude
 - b. elevation
 - c. geological characteristics
3. Soil variables
 - a. soil type
 - b. permeability
 - c. transmissibility
 - d. homogeneity
 - e. composition
 - (1) depth
 - (2) friability
 - (3) humus
 - (4) litter
4. Hydrologic variables
 - a. surface water
 - (1) direct flow
 - (2) storage supplies
 - (3) water quality
 - (4) entrained sediments
 - (5) suspended sediments
 - (6) temperature
 - b. ground water
 - (1) height of water table
 - (2) quantity
 - (3) quality
 - (4) sediments
 - (5) temperature
 - (6) availability
 - (7) transmissibility
 - (8) recharge aspects
5. Ground cover variables
 - a. natural vegetation
 - (1) areal extension
 - (2) developmental stage
 - (3) canopy taxon composition
 - (4) canopy geometry

- b. crop types
 - (1) areal density of plants
 - (2) vertical density of plants
 - (3) growing season
 - (4) cultivation practices
 - (5) irrigation practices
 - (6) drainage
 - (7) availability of water supply
 - (a) amounts and timing

- 6. Management variables
 - a. watershed management
 - b. agricultural management

2.525b Available Data

Sources of data include the entire spectrum of environmental data gathering programs and information banks currently operating. Satellite information sources include LANDSAT and NOAA, the latter being an operational meteorological satellite administered by the National Environmental Satellite System of the National Oceanic and Atmospheric Administration (NOAA). The primary photographic data base consists of large to medium scale photography obtained by the U.C. Remote Sensing Research Program (RSRP). Supplementary image data includes that available from public and private imagery libraries, particularly medium to small scale hardcopy data available through EROS, and Federal, State, and local land management and planning organizations. Ground data are obtained through RSRP group plot sampling, U.S. Geological Survey topographic quadrangles, state and federal meteorological stations, state snow course and snow sensor systems, and the literature.

General information derivable from the above sources presently seems to be adequate to operate specified evapotranspiration estimation models at all three information resolution levels. Data types required for specific models are discussed in section 2.540b. Table 2.5.1b summarizes information sources, derivable data, fetch rates, and remote sensing-aided system information level applications. Appendices III and IV give detailed initial data collection procedures for ground SSU and photo SSU plots, respectively. Expanded characterizations of data input types, quantity, and error rates will be given when documentation on implementation results for specific evapotranspiration models is available.

Data types eventually recommended for use within the remote sensing-aided evapotranspiration estimation system must be available to varying degrees throughout many regions of the world in order to maximize the utility of the proposed technique. In addition they must be cost-effectively obtained, ideally in the context of other data application programs, at fetch-rates utilizable in evapotranspiration models.

TABLE 2.1.5b - EVAPOTRANSPIRATION ESTIMATION DATA TYPES

Information Source	Derivable Data	Highest Fetch Rates	Remote Sensing-Aided Evapotranspiration System Information Level of Application*
LANDSAT (hardcopy and digital data)	1. Vegetation types 2. Terrain types 3. Snow types	Every 18 days	1
NOAA (hardcopy and digital data)	1. Canopy-top temperature 2. Snow surface temperature 3. Cloud-top temperature correlated to precipitation 4. Generalized snow presence data	Twice Daily, 9-10 am and pm LST	1,2,3
Large-medium scale photography	1. Vegetation canopy composition and spatial configuration 2. Ground surface zone characteristics	1 to several times yearly	2
Supplemental Imagery	1. Optional additional canopy and temperature quantification for large area energy flow modeling	multiyear to several times yearly	2,3
Ground Plot Data	1. Canopy geometry 2. Ground surface zone characteristics	multiyear	3
Topographic Data (USGS quadrangles or stereo planigraph output)	1. Elevations	once	1,2,3
Ground Meteorological Station Data USDC, Environmental Data Service; by State	Temperature: Ave. maximum Ave. minimum Ave. Departure from normal Highest (with date) Lowest (with date) degree days Precipitation: Total Departure from normal Greatest day (with date)	Monthly	1,2,3

Table 2.1. 5b (cont)

Information Source	Derivable Data	Highest Fetch Rate	Remote Sensing-Aided Evapotranspiration System Information Level of Application*
USDC Environmental Data Service Local Climatological Data	Temperature: Maximum Minimum Ave. Departure from normal Ave. dew point Degree days Ice on ground at 6am Precipitation: Water equivalent Snow ice pellets Ave. station pressure Wind: Resultant direction Resultant speed Ave. speed Fastest: Speed direction Sky cover Hourly precipitation Station latitude Station Longitude Station elevation	Daily	
California Fire Weather Stations (Fire Weather Observations)	Dry bulb temperature Wet bulb temperature Dew point Relative humidity Fuel moisture Wind speed Wind direction	Daily	
Wildland Fire Danger Rating (Area daily averages, computerized)	Fuel moisture stick 0800 Wind sample 1200 Wind sample 1430 Dry bulb temperature Relative humidity Ave. wind speed 1200 Ave. wind speed 1430 Precipitation Fine fuel moisture	Area daily averages As well as 13-yr. decade ave. for every 10 days for the FDR areas	

Table 2.1.5b (cont)

Information Source	Derivable Data	Highest fetch rate	Remote Sensing-Aided Evapotranspiration System Information Level of Application*
U.S.F.S. Plumas National Forest WB form 612-17	Elevation Dry bulb temperature Wet bulb temperature Wet bulb depression Relative humidity (max,min) Fuel stick moisture Wind direction Wind speed Precipitation Average cloud cover	Daily	
USDA, Forest Service	Total incoming solar radiation	Daily	
Department of Water Resources	Total incoming solar radiation	Daily	
Department of Water Resources (Boulder Creek)	Class "A" evaporation pan data	Monthly for June, July, Aug., Sept.	
Literature	Total incoming solar radiation and some other parameters relating to solar radiation	Daily	
Snow courses and automatic snow sensors	1. Snow depth 2. Snow density 3. Snow water content	Courses: monthly during season Sensors: minutes	2,3
Stream gauging stations	1. Stream flow volume 2. Water yield data	Hourly to Daily	1,2,3
Literature	1. Albedo 2. Energy-water exchange data		1,2,3

* Legend: 1 = information level 1: LANDSAT level of information resolution
 2 = information level 2: large scale photograph level of resolution
 3 = information level 3: ground level of information resolution

2.530b Description and Brief Evaluation of Current Models for Evapotranspiration Estimation

Planning for the optimum utilization of available water supplies involves consumptive use of water as its basic precept for the future development of any area, whether it be for irrigation, flood control, power production, municipal use, recreational use, or for multiple purposes.

A large number of methods have been used to estimate evapotranspiration. In applying these methods it is usually necessary to make assumptions with respect to at least one of the variables. It is important that these assumptions are not overlooked, particularly when methods are being transferred from one watershed or field of investigation to another. The accuracy with which each term in the equation can be evaluated is another important consideration; this varies from one method to another.

A very brief review of the main methods will be discussed in this section; a more complete discussion of the methods can be found in Appendices I and II. This description will provide the baseline against which to judge the applicability of each model type to a remote sensing-aided evapotranspiration system in general and also the applicability of each to the three levels of information resolution within that system, specifically.

2.531b Water Balance

This method is used for both terrestrial and water surface evaporation measurement. It is based on a hydrological equation, which is usually considered on a large scale or on a catchment basin basis. In this method water gain (precipitation, stream input) balances water loss (stream flow, evapotranspiration, water in solid form, subsurface storage) and by knowing the ways that water is lost evapotranspiration can then be measured or estimated.

The primary use of this model in the remote sensing-aided system will be to provide an equation of estimated water input versus loss on a watershed basis. The difference will represent estimated water yield for the watershed or sub-watershed of interest. Predicted precipitation, snow water content loss, evapotranspiration water loss, and subsurface flow water loss based on the remote sensing-aided approach described earlier will be substituted into the water balance equation to give water yield.

2.532b Energy Balance

The energy used in evaporation, LE , is the product of the latent heat of vaporization, L , and the mass loss of water, E . This energy must be supplied from the energy sources (solar and advected). Since

the ideal surface is only two-dimensional, conservation of energy requires that as much energy reaches the surface as leaves the surface. The other sources and sinks of energy are the net radiant energy gained or lost; that gained or lost by air above the surface; heat gained or lost by soil and vegetation, and heat used in metabolism (mainly photosynthesis minus respiration). Melting or freezing of snow also acts as a heat sink or source, which usually is not considered in the energy-balance equation. The energy-balance method is based upon the conservation and flow of energy between the above mentioned components. Therefore the energy used for evapotranspiration and consequently the amount of evapotranspiration can be estimated.

Since the heat flux to the air is as difficult to measure as evapotranspiration itself, the Bowen ratio, defined as the ratio of heat flux to the air to LE, is used for estimation of evapotranspiration. This method is called the energy-balance method using Bowen ratio, β .

2.533b Aerodynamic Methods

These techniques assume similarity of the flux of momentum, heat, and water vapor. This assumption is not always justified and is almost always troublesome.

It is assumed that these fluxes are proportional to the vertical gradients of horizontal wind speed, temperature, and specific humidity. It is also assumed that the transfer coefficients of diffusivities for momentum, water vapor and wind are equal; therefore, evapotranspiration may be evaluated from the associated water vapor flux equation if simultaneous measurements of the gradients of temperature, wind movement and water vapor are made at the same site.

The assumption of similarity in eddy transfer coefficients for momentum, water vapor, and heat holds reasonably well only during near neutral or non-buoyant conditions of stability. Conditions of neutral stability are common at sunrise and sunset and occur seldom, if ever, during periods of high evaporative flux. However, a stability correction factor might be considered for better results.

Aerodynamic equations may be combined with other approaches such as the empirical and energy balance formulations to form a more comprehensive model for evapotranspiration prediction.

2.534b Combination Methods

This title is usually given to a group of rational methods which are derived from a combination of energy-balance and aerodynamic methods. Some of the best known combination methods are those of Penman (1948), Ferguson (1952), Slatyer and McIlroy (1961), Priestly and Taylor (1972), and McNaughton and Black (1971, 1972). The Penman and Ferguson methods give estimates of free water evaporation while others can be used to estimate actual evapotranspiration.

Modified Linacre Method: Stephan and Stewart (1963) appear to be the first specifically to associate the ratio LE/Q_s with the mean ambient temperature, T , where LE is evapotranspiration and Q_s is the total incoming solar radiation (Linacre, 1967). Their observations were quickly followed by the results of several other investigators. Linacre (1967) deduced the ratio LE/Q_s by means of four basic equations. The first is analogous to Penman's formula for lake evaporation; the second concerns the net-radiation flux, Q_n , expressed in terms of its components; the third is an equation for the net upward flux of longwave radiation, Q_{nL} ; and the fourth is an approximation for the solar radiation flux, Q_s . The final formula for estimating ET/Q_s in this method employs temperature, ambient saturation vapor deficit, a cloudiness term, and the type of surface cover in terms of aerodynamic and vegetation resistances as well as albedo.

Of the general group of combination methods it may be said that they are readily adaptable to the generalized estimation of evaporation from an area. It should be borne in mind, however, that loss of accuracy to some extent is inevitable, particularly where there are spatial variations in meteorological conditions, available soil moisture and types of vegetation.

2.535b Empirical Methods

Any formulas based on empirically determined coefficients are called empirical methods. Estimation of evapotranspiration based on empirical equations may be realistic only for localities and time periods for which the coefficients used in these equations were developed. Potentially serious errors may occur in extrapolation of results to other regions and shorter periods of time. On the other hand, several general methods for estimating evaporation or evapotranspiration have been developed which require only minor modification to be applicable to local situations where an appropriate weather record exists. These are the models most often applied to agricultural surveys. Some of the empirical methods will be mentioned in the following discussion, but more detail may be found in Appendices I and II.

Thornthwaite uses mean temperature and a monthly heat index for estimating potential evapotranspiration. This method has several shortcomings, including a lag of actual with calculated evapotranspiration.

Blaney and Criddle, by correlating plan evaporation with monthly mean temperature, relative humidity, and percentage of the total yearly daylight hours for each individual month, derived an empirical consumptive use index. They assumed that water supply to the growing plants never becomes limiting. This method is easy to use, necessary data are readily obtainable, and results have been sufficiently accurate for many practical applications.

The original Penman equation has been applied fairly successfully in a range of climates. The Penman method combines aerodynamic and energy-balance approaches and the components of his equation are net radiation, an aerodynamic term, and some standard meteorological parameters. The form of the aerodynamic term has been changed since the equation was first proposed. For free water evaporation Penman (1956) used an empirical equation to estimate the aerodynamic term from wind movement. The above-mentioned version of the Penman equation gives the evaporation estimates for a freewater surface, and consequently an adjustment factor is required to estimate potential evapotranspiration.

Limitations of the Penman equation (such as defining potential evapotranspiration rates, inadequacy of application to natural vegetation surface, requirement of wind data, and so on) may be found in Appendix II.

The modified Penman, McIlroy et al. equations represent more realistic models of transpiring plants in the atmosphere than does the original Penman type. But the introduction of crop surface and soil-water parameters serves chiefly to complicate the estimation procedure, and unless these parameters are evaluated for conditions at the site for which evaporation estimates are required, then estimation is still essentially empirical.

In the Slatyer and McIlroy equation, apart from the convenience of using wet-bulb depression instead of saturation deficit, the essential difference is that several factors, including vapor atmospheric conductance, neglected by Penman are taken into account. Evaluation of the wind function with regard to McIlroy's equation is the major difficulty of applying this technique, whereas other measurements required are simple and can be obtained from climatological stations.

McNaughton and Black (1971) applied a modified form of the Van Bavel (1966) combination model to an experimental Douglas fir forest in British Columbia, Canada. They also used the Monteith (1965) model, which introduces the effect of plant stomatal diffusive resistance to vapor flow by considering the vegetative canopy as a single extensive isothermal leaf. Following a similar procedure to Penman (1948), and utilizing Monteith and Von Bavel equations, McNaughton and Black developed a formula for forest evapotranspiration. The McNaughton and Black model attracted criticism because of considering only one layer of the canopy, and consequently ignoring leaf boundary layer diffusion resistances and aerodynamic diffusion resistances between different levels of the canopy.

Priestly and Taylor (1972) have reviewed several experiments over surfaces where surface resistance was expected to be negligibly small and evaporation from the free water surface was expected to be equal to the actual evaporation rate. They developed an equation identical to the final equation of McNaughton and Black (1971). Their experimental data was then used to determine the value of their equation's single empirical coefficient that gave the best fit possible to observed evapotranspiration.

A realistic estimate of the influence of intercepted water was obtained by comparison of the McNaughton and Black model with the Priestly and Taylor formulation. As a result, a more complete model which includes the importance (quantity) of interception losses by the forest was made by McNaughton and Black.

Hargreaves (1956) developed an empirical equation based on relative humidity, a monthly day length coefficient, and the mean monthly temperature. The Hargreaves formula provides a simple and reasonably reliable method of calculating evaporation under a fairly wide range of conditions. Hargreaves estimated evapotranspiration by multiplying the computed or measured pan evaporation by a monthly coefficient. The model therefore has implicitly integrated many of the effects of the different climatic factors.

Christiansen et al. (1966) developed an empirical formula for estimation of evapotranspiration by multiplying a set of factors. These factors are a set of dimensionless constants determined from theoretical values of the solar radiation reaching the earth's outer atmosphere, and a dimensionless empirical coefficient determined from the product of any number of subcoefficients each expressing the effect of given climatic or other factors. Christiansen's formula produces good results when data are available for temperature, wind, humidity, percent of possible sunshine, and elevation. But by using the relationship (empirical) between some of the above-mentioned parameters, the formula can provide acceptable results, given only data for temperature and elevation.

The Jensen and Haise (1963) model uses total short-wave solar radiation as its climatic factor and a dimensionless crop coefficient to estimate potential evapotranspiration. A somewhat similar equation has been proposed by Turc (1961) for computing potential evapotranspiration from solar radiation and temperature.

The semi-empirical methods based on solar radiation are essentially energy-balance methods, being formulated on the fact that the principal source of energy for evapotranspiration is incoming solar radiation. These methods are more reliable for both short and long-time periods than those using meteorological parameters that are not a measure of available energy, basic components of energy-balance, and/or mass transfer.

Turc (1954) suggests an equation for estimating annual evapotranspiration based on annual precipitation and L , a function of mean annual temperature. Pike (1964) tested Turc's method in forested watersheds in Malawi, and found that it underestimated actual ET by amounts ranging from 6 to 17 percent. He modified Turc's formula by introducing Penman's E instead of L , or utilized data from adjusted evaporation pans. Lewis (1968) used Pike's equation to evaluate consumptive use in the Placer County, California watersheds. He used Penman's E values for 10 months (October-July) for ET estimation on oak woodlands. Estimates of ET by Lewis departed from actual values by 3 to 34 percent (Burgy and Papazafirion, 1971).

2.540b Recommendations for Evapotranspiration Model Applicabilities to Information Resolution Levels within the Remote Sensing-Aided Evapotranspiration Estimation System

Based on the discussion in section 2.530b and in Appendices I and II the following recommendations can be made for current evapotranspiration model applicability to the information resolution levels within the remote sensing-aided evapotranspiration estimation system. The models recommended for level one will be used to provide evapotranspiration estimates for individual base resolution elements which are the size of the LANDSAT pixels. Those recommended for levels two and three will generate estimates for individual SSU photo and ground plots respectively.

2.541b Model Recommendations for Level I

Empirical formulas will be applied in this level, particularly using methods based on the:

Jensen and Haise equation
Hargreaves equation
Blaney-Criddle equation
Turc equation.

The input for these models comes primarily from LANDSAT, meteorological satellites, ground meteorological stations, and digitized topographic data. The variables to be derived from these data for the above models are surface temperature (daily average, minimum, maximum), all radiation components, relative humidity and cloud cover. These data will be obtained and processed as described in sections 2.100b, 2.520b, and 2.530b as well as in Appendices I and II.

The general reasons for choosing the above models for the first information resolution level are (1) the availability of needed input data on a watershed-wide basis from the satellites and (2) the maximization of physical realism when compared to other empirical models. Specific reasons for selection of the above three models are as follows.

- a. Desirable attributes of the Jensen and Haise equation include:
 - (1) use of solar radiation, a variable highly correlated to evapotranspiration, as a primary variable,
 - (2) based on the first law of thermodynamics (energy conservation), which has been repeatedly shown to be a reliable and conservative method of determining evapotranspiration for both short-term and long-term periods,
 - (3) based partially on energy balance and therefore is semi-physically realistic (that is semi-empirical), a situation that may maximize reliability over time,

- (4) most input variable data may be derived from satellite information according to transformations outlined earlier,
- (5) a comparison of results with and without using remote sensing techniques may be possible, thus allowing evaluation of the performance of the remote sensing-aided systems, and
- (6) allows a calculation of potential evapotranspiration which may be input to more sophisticated models or which may be used in information levels two and three to check the performance of models utilized there.

b. Desirable attributes of the Hargreaves equation include:

- (1) one of the most practical and useful procedures for estimating plant consumptive water use according to Christiansen (1966),
- (2) has been shown to give good results when checked against other methods (see Appendices I and II),
- (3) since it is originally based on pan evaporation data, it integrates climatic and other factors important to the evapotranspiration process,
- (4) most needed data inputs can be supplied by satellite information, and
- (5) required meteorological data include temperature and humidity, or temperature only, since humidity may possibly be derivable from temperature; frequent ground station values for temperature and in some cases humidity are available to calibrate meteorological satellite surface temperature and humidity values derived from satellite temperature data.

c. Desirable attributes of the Blaney-Criddle equation are:

- (1) uses same data as the Hargreaves equation; therefore could be used as check against Hargreaves' equation,
- (2) used extensively within and outside of the U.S.,
- (3) has been applied to a range of climate with reasonably successful results, and
- (4) remote sensing data inputs (for level one, satellite data inputs along with calibrating ground information) can supply most of the information required.

2.542b Model Recommendations for Level II

The basis for the evapotranspiration models to be applied to the second level of information resolution is that of energy conservation, which is a proven law of thermodynamics. For this level, the energy-balance method will be combined with other methods for consideration of vegetation canopy effects and advected energy processes. The objective of the model applied at level two will be to capitalize on vegetation canopy, geometry-composition, and other surface data available from aerial photography to provide improved evapotranspiration estimates. The following models are being examined for application:

Priestly and Taylor
McNaughton and Black
Modified McIlroy and Slatyer Model
Linacre Equation
Models to be developed using radiation as the primary variable

Justification for the use of these methods at this level is as follows:

- (1) they are based on the first law of thermodynamics,
- (2) these models are based on physical relationships and consider some parameters which the empirical methods do not, such as
 - (a) resistance of all the stomata of canopy leaves, and
 - (b) aerodynamic resistance,
- (3) the McNaughton and Black model has been applied to a forest watershed vegetation type with acceptable results,
- (4) the Priestly and Taylor model is based on a survey of a large number of experiments over various surfaces and climatic conditions; the results have agreed with the McNaughton and Black model; in addition, the Priestly and Taylor model utilizes solar radiation, a highly evapotranspiration correlated variable, as its primary input, and
- (5) the McIlroy and Slatyer method is one of the well known combination methods; it has been shown to be a rational model giving acceptable results by experts in the field.

The variables to be estimated for input to the above models are much more canopy and ground surface specific than those required for level one. In general, input variables to be applied in level two must be determined more precisely and more frequently as well. Data requirements include temperature, humidity, and wind value profiles in the soil surface-vegetation zone. Wind friction velocity, rainfall, ground cover, and topographic data must also be obtained.

These canopy data requirements will be fulfilled in large part through large scale photographic measurements collected from photo second stage sampling units and calibrated by corresponding ground data. Canopy-top meteorological data will be obtained as in level one, viz. through meteorological satellite data calibrated by ground station information and by microclimatic functions extrapolating satellite and ground data values to SSU's of interest. Vertical meteorological variable profiles within the canopy will be generated from canopy-top data according to canopy geometry functions.

2.543b Model Recommendations for Level III

The third information resolution level in the LANDSAT-aided evapotranspiration estimation system will allow application of the most sophisticated models. The approach will be to select and develop those evapotranspiration estimation equations which are most rational and physical in terms of the actual processes involved. A combination of empirical, energy balance, and aerodynamic methods will be applied at this level.

In addition, a new model will be developed and tested against other techniques. It will be based on a combination of methods using radiation energy and temperature as primary variables (e.g. Jensen and Haise equation) and on methods considering vegetation canopy effects and aerodynamic resistance (e.g. Priestly and Taylor equation, McNaughton and Black equation, and McIlroy and Slatyer equation). This new model will be constructed so as to take best advantage of the data gained through remote sensing and ground sampling.

Both the new model formulation and the combination of rational methods using energy and radiation will be designed to give the most precise and accurate evapotranspiration estimates possible based on level three information. Canopy-top meteorological input to sub-canopy profiling functions will be obtained as for models operating on level one data. Required variables to be estimated are similar to those required of level two models. However, some additional data for subcanopy and vertical meteorological profiles must be obtained.

2.550b Summary and Future Work Related to Evapotranspiration Estimation

The sampling framework has been proposed for a remote sensing-aided evapotranspiration estimation system designed to give timely, relatively accurate, cost effective evapotranspiration estimates on a watershed or sub-watershed basis. The system employs a basic two stage, two phase sample of three information resolution levels to estimate this important water yield-water use related quantity.

A necessary documentation of assumptions, structure, and limitations of current evapotranspiration models has been performed. Based on this analysis recommendations have been made concerning the applicability of these models to evapotranspiration estimation at various information levels corresponding to given stages and phases of the sampling design.

Factors affecting evapotranspiration have been identified. Current data sources and available data types necessary to support evapotranspiration estimation are listed.

Based on the foregoing design, documentation, and feasibility analysis, work is not proceeding to implement the remote sensing-aided system. Effort will be focused on refining the sample design, developing in detail supporting data flow mechanisms, and adapting evapotranspiration models to their respective information levels.

The input data for models requiring spatial information will be provided by a computer data bank. The RSRP software for this data bank, known as MAPIT, will allow a geometrically coincident combination of LANDSAT-related data, meteorological satellite data, ground meteorological station data, ground sample unit information gathered by RSRP and others, and topographic data.

Input data sets and evapotranspiration estimate output will be coordinated with concurrent sensitivity analyses of State of California water yield models performed jointly by the Davis and Berkeley NASA Grant groups. Initial data set location will be specific to the Spanish Creek Watershed, a representative subarea of the Feather River Watershed. Later expansion to the entire Feather River Watershed, the NASA Grant water supply test site, will occur after the economical testing on the smaller basin is completed.

The final product will be a documentation of any improvements in accuracy, timeliness, and cost considerations for the determination of water yield attributable to the remote sensing-aided evapotranspiration estimation system. Results will be specific to the state-of-the-art hydrologic models under examination.

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2.600b RSRP METEOROLOGICAL SATELLITE DATA INVESTIGATIONS

Meteorological data, particularly meteorological satellite data, when combined with ERTS or conventional photographic and ground data sources, can potentially provide significant gains in remote sensing information usefulness to renewable resource inventory and modeling. Modeling abilities for evapotranspiration, snow dynamics, vegetative growth, and insect infestation dynamics, to name just a few, are much enhanced.

Therefore, the Remote Sensing Research Program (RSRP) is presently investigating the problems involved in integrating real-time meteorological satellite information into the water supply analysis. Work is presently proceeding to install a high quality phone line between the National Weather Service (NWS) Satellite Field Services Station (SFSS) Redwood City, California and the RSRP Lab in the Space Sciences Laboratory building at U.C. Berkeley. Daily reception of Geostationary Environmental Satellite System (GOES) data at the NWS station will be transmitted in an analog mode over the phone line to RSRP. Analog recorders will be automatically set to receive the transmitted data. After cataloging, the GOES data for snow or evapotranspiration estimation dates of interest will be translated to digital form for merging with LANDSAT and other data sets.

A one month test of this system is now scheduled for late 1975. Signal quality as received at Berkeley will be compared with signals recorded directly from the NWS transmitting devices at Redwood City. In addition, analog data will be compared with copies of direct satellite reception data in digital form. If signal degradation on the phone line is not significant, the system will be utilized on a selective basis to acquire real-time information for hydrologic parameter estimation. Otherwise, GOES digital data will be acquired from NWS Redwood City on a selective basis.

In addition to the GOES information, digital data from the higher resolution NOAA meteorological satellite series will also be obtained on a selective date basis. The NOAA Very High Resolution Radiometer (VHRR) data will be obtained through a tape copying arrangement with the SFSS in Redwood City. VHRR digital information acquisition is planned for LANDSAT overpass dates in the April through June snowmelt period for the West Coast region. The data will be eventually merged with the LANDSAT and supporting information for use in the development of techniques for water loss estimation.

In order to provide a data base for a full test of remote sensing data type applicability to hydrologic modeling, two dates have been selected for coordinated image acquisition. The first of these will be in July 1975. Time-coincident passes of high-flight thermal scanner, NOAA,

and LANDSAT sensors over the Spanish Creek Watershed and the Central Sierra Snow laboratory are planned for this summer date. The useful information content from each sensor will be compared and contrasted in the context of the water loss estimation approach outlined above. The summer data will also provide a reference plane for the second time-coincident pass in May 1976. The same sensor set will be examined for utility in water loss estimation. Analysis of GOES digital data for the second date and, if possible, for the first date is also planned.

It should be noted that high-flight thermal scanner passes over the San Francisco Bay Delta Region have been requested for the same dates specified above. This information is designed to help lay the foundation for developing new remote sensing-aided water quality quantification technique development in that region.

One of the major goals of meteorological satellite information acquisition will be to build a significant research data set for the California region. The NOAA satellite provides VHRR data in a visible channel ($.6\mu - .7\mu\text{m}$) twice daily (approximately 9:30 a.m. and 9:30 p.m. (LST) with a nominal pixel resolution of 930 meters at the nadir. GOES data is nominally available every 30 minutes with nadir resolutions of 1/2 to 2 miles in the visible and 4 miles in the thermal infrared. The scanned swath ranges from horizon to horizon. Such an information bank can serve as a valuable source of remote sensing data for many disciplines in addition to hydrology.

RSRP proposes to systematically address the implementation problems of this new data bank. These include image rectification, ground station calibration of NWS satellite data for meteorological parameters of interest, and microclimatic transforms to fractionate meteorological pixels into smaller subpixel resolution elements. Pattern and spectral analyses of NWS satellite cloud formation data also will be conducted in order to develop rainfall intensity correlations.

2.700b WATER SUPPLY MODEL DEFINITION AND PERFORMANCE EVALUATION

Documentation of the California Joint-Federal State River Forecasting Center (RFC) Sacramento hydrologic model and the California Cooperative Snow Survey (CCSS) volumetric and dynamic water yield models and associated driver parameters was given in the May 1, 1974 report for this NASA Grant. Additional analyses of model structure and driver variables may be necessary to fully refine remote sensing-aided water loss estimation procedures and the set of variables considered. In addition, another RFC model, the Antecedent Index (AI) model, may require documentation as it is of historical importance in the Feather River Watershed. The AI model may be used as one of the baselines against which to judge performance of the new RFC Sacramento hydrologic model.

Documentation of the CCSS volumetric water yield model prediction accuracy and precision for the Feather River Watershed is available in Chapter 6, section 6.350. Further analysis of this procedure's performance will be conducted over the next year. Agreement has been reached with RFC to analyze the performance of their model, taking care to consider all the contextual assumptions involved in its use in water yield forecasting. Performance documentation for the RFC AI model results for the 1973-74 and/or the 1974-75 water year for the Feather River Basin will be performed first. Then a performance evaluation, documenting real-time assumptions for AI and Sacramento hydrologic models operating in the water year concurrent to the investigation will be conducted. These performance analyses will provide a measure against which to judge water supply model performance when remote sensing data are included.

2.800b CONTINUING RSRP GRANT WATER SUPPLY WORK

The six continuing aspects for this work are as follows:

1. Continued state-of-the-art water supply model definition and performance documentation. This effort, carried out in conjunction with the Algazi-Burgy Group, is necessary to fully refine the remote sensing-aided water loss estimation procedures and the set of variables considered. Both the California Joint Federal-State River Forecasting Center (RFC) Sacramento hydrologic model and the California Cooperative Snow Surveys (CCSS) hydrologic models continue to be examined. Performance documentation continues for the CCSS models and performance for the RFC model will be stated concisely in the context of the forecast assumptions.

Inspection of current water quality prediction methodologies may also be begun. As stated in Chapter 2a and Chapter 5, the water quality question is of growing importance in water resources management, and especially in managing the California Water Project. Water quality determination and prediction is thus a viable subject area for potential analysis in the current NASA sponsored study. Previous remote sensing water quality work in the Delta includes that by Draeger, Benson, & Johnson (1974) and that by Johnson, (1974).

2. Continued development and testing of the remote sensing-aided water loss estimation system. This work includes sample design plus technique development for estimation of watershed snow areal extent, snow water content, evapotranspiration, impervious surface area, and effective precipitation input. The data set initially includes the Spanish Creek Watershed

for efficiency testing purposes, but will be expanded to include ultimately the entire Feather River basin.

3. Sensitivity analysis for critical parameters in water supply models. In coordination with the Algazi-Burgy Group, RSRP is developing water parameter (water loss) estimates to be included in current RFC and CCSS hydrologic models. The performance change in the models with and without these remote sensing-aided estimates as determined on the Davis system will be noted. Feedback on model performance will allow modification of the remote sensing-aided water parameter estimation sampling design and methodology so as to improve hydrologic model performance.
4. Determine the costs of information gathering using conventional and remote sensing-aided methods. This effort continues especially in the context of the RFC Sacramento River model and the CCSS volumetric model. Cost data on semi-automatic remote sensing-aided basin snow areal extent, snow water content, evapotranspiration, and manual impervious surface area estimation is especially emphasized.
5. Perform cost-effectiveness analyses with respect to conventional and remote sensing-aided water supply estimation systems. In the near run, systems for estimation of intermediate parameters used in ultimate water yield prediction will be compared. In the longer run, systems actually producing water runoff estimates will have comparative analyses performed. Coordination here will be especially strong between RSRP and Social Science Group personnel.
6. Contribute to cost-benefit studies to determine the impact on society resulting from changes in water supply information caused by the application of remote sensing techniques to water supply models. RSRP will contribute cost and performance data, in conjunction with the Algazi-Burgy Group, to the Social Sciences Group for cost-benefit impact studies.

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**APPENDIX I: DERIVATION, DESCRIPTION, AND DEFINITION OF INPUT PARAMETERS
FOR CURRENT EVAPOTRANSPIRATION ESTIMATION AND SOLAR RADIATION
EQUATIONS**

Siamak Khorram

APPENDIX I: DERIVATION, DESCRIPTION, AND DEFINITION OF INPUT PARAMETERS FOR CURRENT EVAPOTRANSPIRATION ESTIMATION AND SOLAR RADIATION EQUATIONS

I 1.00 INTRODUCTION

In order to understand the applicability of various types of evapotranspiration estimation equations to a remote sensing-aided system, a baseline definition and discussion of those equations is necessary at the outset. The information in this appendix forms a comprehensive review of current evapotranspiration methodologies. For efficiency, however, it focuses on those aspects of each approach which are either relevant to a remote sensing-aided multistage estimation procedure or which are important in understanding the appropriateness of such applicable techniques.

I 2.00 GENERAL CURRENT APPROACHES TO EVAPOTRANSPIRATION ESTIMATION

Various methods have been used to measure the amount of water consumed by natural vegetation. Regardless of the method used, numerous problems are encountered.

Evapotranspiration can be measured or estimated in both direct and indirect methods. The estimation of evapotranspiration by means of atmometers (to be defined later), pans or tanks, computational methods and water balances are considered to be "direct" methods. Other methods which are generally based on energy balance and aerodynamic approaches are considered to be "indirect" methods. Meteorological methods are those methods which are generally based on meteorological parameters, (e.g., solar radiation), as opposed to micrometeorological, (e.g., specific humidity) and are mostly applied to indirect and empirical methods.

Meteorological methods in general have several distinct advantages for determining evaporation and transpiration from natural or cultivated surfaces. Meteorological methods are generally nondestructive, and thus can be employed continuously, or they can be used for sampling at a given site. They do not contain assumptions concerning the wetness of the surface or the status of the soil water. They are capable of yielding relatively accurate short period rates, and, in addition, they supply part of the meteorological information mandatory to understand the results. Meteorological methods also have disadvantages. They are not integrating and require continuous measurement of several parameters, some of which are difficult to measure. The nature of the equations and parameters requires repeated solution rather than the use of long-period averages, and the initial cost of ground sensors and recording equipment is high.

Here is a brief discussion of some of the methods considered for evapotranspiration estimation.

1 2.10 Water Balance

This method is based on the hydrological equation, which is usually considered on a large scale or on a catchment basin basis. The basic equation is:

$$E = P - Q - D - \Delta S$$

Where P is precipitation falling on the evaporating surface, Q is the net surface runoff, D is the net underground drainage, ΔS is the change in soil water content, and E is evapotranspiration.

With the equipment such as evaporation pans, lysimeters, stream gauges, precipitation gauges, and soil moisture measuring devices, the parameters of interest can be controlled or measured accurately; therefore, a reliable measurement of point evapotranspiration can be gained. Methods of soil moisture measurement may be divided into two groups: in situ methods, in which observations are obtained with remote sensing-aided techniques, and the methods which necessitate taking a sample of soil.

I 2.20 Energy Balance

The radiant energy reaching the earth's surface consists of shortwave radiation from the sun (whether direct, scattered by the atmosphere and its pollutants, or reflected from clouds) and longwave radiation from the atmosphere and the clouds. The net radiation at the surface resulting from the difference between the incoming and outgoing quantities is then used:

(1) as sensible heat in raising the temperature of vegetation, soils, and other objects on the surface, which in turn transfer a proportion of this heat to the atmosphere;

(2) as latent heat in evaporating water from vegetation and surface, which is also transferred to the atmosphere; and

(3) as energy in the biochemical plant processes, photosynthesis and respiration.

The basic energy balance equation is:

$$R_n = H + LE + G + CP$$

Where R_n is the net radiation flux received at the surface, H is the sensible heat flux, LE is the latent heat flux (L being the latent heat of evaporation),

G is the heat flux into the soil, and P is the net rate of photosynthesis (C being the chemical energy storage coefficient). It is usual to neglect CP but it can be measured if necessary.

1 2.30 Energy Balance with Bowen Ratio

As H is generally just as difficult to measure as E, it is expedient to use the Bowen ratio $\beta = \frac{H}{LE}$, which can be evaluated in terms of the ratio of the vertical gradients of temperature and specific humidity. Considering

$$H = C_p \rho K_h \frac{\partial T}{\partial z}$$

and

$$LE = L_e K_w \frac{\partial e}{\partial z}$$

$$\beta = \frac{H}{LE} = \frac{C_p \rho K_h \frac{\partial T}{\partial z}}{L_e K_w \frac{\partial e}{\partial z}}$$

Where C_p is the specific heat of the air at constant temperature, ρ_a is the density of moist air, K_h is the eddy diffusivity of air, ϵ is the ratio of the mole weight of water vapor to that of dry air, and K_w is the eddy diffusivity of water vapor. Assuming K_h (heat) = K_w (water) we can replace the gradients by finite differences measured over the same distance. Therefore, the energy balance equation is

$$R_n = G + LE + \beta LE$$

and consequently

$$LE = \frac{R_n - G}{1 + \beta}$$

Another assumption involved in the Bowen ratio method is the constancy or similar variation with height of the fluxes H and E from the surface to

the upper measuring point.

Use of the Bowen ratio eliminates any need for wind measurements, known heights, stability corrections, roughness length, or zero plane displacement; but determination of the difficult vapor concentration difference is required.

I 2.40 Aerodynamic Equations

This method is based on the similarity of heat, water vapor, and momentum transfer throughout the atmosphere. In each case, the flux in the equation is proportional to the vertical gradient of temperature, water vapor, and wind speed, respectively.

The equations governing these transfer processes are:

$$H = - c_p \rho K_h \frac{(\partial T)}{\partial Z}$$

$$E = -\rho K_w \frac{(\partial q)}{\partial Z}$$

$$\tau = \rho K_m \frac{(\partial u)}{\partial Z}$$

where H is the sensible heat flux, E is the water vapor flux, τ is the momentum flux. The terms in parentheses represent the vertical gradients or change with height Z, of air temperature, T; specific humidity, q; and wind speed, u. The density of the air, ρ , and its specific heat, c_p , are considered constants. The transfer coefficients or diffusivities, K_h (heat), K_w (water), and K_m (momentum), vary with wind-speed, surface roughness, height, and sensible heat flux.

The three transfer coefficients are closely related, since all are dependent on the turbulent properties of the atmosphere. Many experiments

have shown that

$$K_m = k' U_* Z / \phi_m$$

where k is the von Karman constant, ϕ_m is a stability correction, and U_* is a form of momentum flux called the friction velocity, which is defined as

$$U_* = (\tau/\rho)^{\frac{1}{2}} \quad \text{eq. 1}$$

When the sensible heat flux, H , is zero (neutral or adiabatic condition), then the stability parameter, ϕ , is unity. This case is the regime of forced convection in which turbulence is produced only by friction due to wind movement over the rough surface. When H is positive (the unstable or lapse condition), free convection due to rising warm air and sinking cold air increases the turbulence, which effectively decreases ϕ to some value less than unity. When H is negative (the stable or inversion condition), the turbulence is damped and ϕ increases to a value greater than unity.

By an analogy called the similarity hypothesis, the other two diffusivities are similarly defined as

$$K_h = k U_* Z / \phi_h \quad \text{eq. 2}$$

$$K_w = k U_* Z / \phi_w$$

Many scientists assume $\phi = \phi_m = \phi_h = \phi_w$, and thus $K = K_m = K_h = K_w$ as a satisfactory first approximation.

Another unsolved micrometeorological problem is the form of ϕ under varying stability conditions. Usually ϕ is given as a function of other stability parameters such as the Richardson number or the Monin-Obukov dimensionless height.

A practical consideration of stability is given by Tourin and Shinn (1969) who specified the following stability ratio.

$$SR = \frac{\Delta T}{(\bar{U})^2} \text{ in } ^\circ\text{C Sec.}^2 \text{ m}^{-2}$$

where SR = stability ratio, ΔT = the temperature change, and \bar{U} in the mean wind speed. They found good agreement of SR ratios with Richardson numbers where values of $SR < -0.005$ indicate unstable conditions, $SR > +0.005$ indicate stable conditions, and SR ratios between -0.005 and $+0.005$ are indicative of near-neutral conditions. (Avery, et al. 1971).

The friction velocity, U_* , can be found from the integrated form of the combined equations of 1 and 2

$$U_* = \frac{R(U_2 - U_1)}{1_n [(Z_2 - D) / (Z_1 - D)] - \Psi} \quad \text{eq. 3}$$

where

$$\Psi = \int_{Z_1 - D}^{Z_2 - D} \frac{1 - \phi}{Z} \phi Z$$

and U_1 and U_2 are wind speeds measured at two heights above the canopy, Z_1 and Z_2 . Ψ is the integrated form of the stability correction, which depends on Z_1 and Z_2 . The zero-plane displacement, D , is a correction to the measured heights of the sensors above the ground, Z_1 and Z_2 . D is approximately equal to the general height of the vegetation and allows for the fact that the top of the canopy, (not the ground level), influences the wind above the trees.

Substituting equation 3 into equation 2, and then substituting the result into

$$E = - \rho k_w \frac{\partial q}{\partial z}$$

and integrating gives the mass transfer equation for E as

$$E = - \rho k^2 \frac{(u_2 - u_1) (q_2 - q_1)}{\left(1_n \frac{z_2 - D}{z_1 - D} - \psi\right)^2}$$

in which $(q_2 - q_1)$ is the difference between specific humidity at heights z_2 and z_1 and ϕ_w is set equal to unity for the neutral condition.

This equation can be used directly for finding evapotranspiration.

Bulk aerodynamic methods use surface values, $u_1 = 0$, $(z_1 - D) = z_0$, the roughness length, and $q_1 = q_0$, in the form of

$$E = - \rho k^2 \frac{u_2}{\left(1_n \left(\frac{z_2 - D}{z_0}\right) - \psi\right)^2} (q_2 - q_0)$$

$$= f(u_2) (q_2 - q_0)$$

This method involves only wind-speed on one height, but requires constancy of surface roughness.

1 2.50 Combination Methods

The best known methods combining energy balance and aerodynamic approach are those of Penman (1948), Budyko (1956), Ferguson (1952), and McIlroy

(Slatyer and McIlroy, 1961). The Penman and Ferguson methods give estimates of free water evaporation while that of McIlroy et al. can be used to estimate actual evapotranspiration. A later version by Penman (1961) also enables an adjustment for surface humidity but this remains primarily untested.

1 2.51 Penman Method

The original Penman equation has been applied fairly successfully in a range of climates (Hounam 1971).

The generalized equation is:

$$E = \frac{\Delta R_n + E_a}{\Delta + \gamma}$$

where E is the evaporation from free water surface, Δ is the slope of the saturation vapor pressure versus temperature curve (that is $\Delta = \frac{de_a}{dT_a}$ where e_a is the saturation vapor pressure at the air temperature T_a). However, the transformation of wet bulb and dry bulb temperatures into actual vapor pressure can be done by using the simplified Ferrel equation (List, 1958)

$$e = e_{stw} - 0.66 (T_a - T_w)$$

where e = actual vapor pressure, e_{stw} = saturation vapor pressure at the wet bulb temperature, T_a = the dry bulb temperature in °C, and T_w = the wet bulb temperature in °C. Both e and e_{stw} are in the same pressure units. R_n is the net radiation flux received at the surface, γ is psychrometric constant, and

$$E_a = f(U) (e_a - e_z).$$

E_a is the aerodynamic component, where e_a is as defined previously, and e_z is the actual vapor pressure of the air. The psychrometric constant may be expressed as

$$\gamma = \frac{C_p}{L}$$

where C_p is the specific heat of air at constant pressure and L is the latent heat of vaporization.

The form of aerodynamic term $f(U)$ has been changed since the equation was first proposed but, for free water, Penman (1956) used

$$f(U) = 0.35 (0.5 + U_2/100)$$

Where U_2 is the wind run in miles per day set two meters above the surface.

The above-mentioned version of the Penman equation gives an estimate of evapotranspiration from free surface, E_o , but by use of a factor $f = E_t/E_o$ an estimate of potential evapotranspiration E_t may be obtained. Values of F , deduced by Penman for West Europe are 0.80 for summer, 0.60 for winter and 0.70 for the equinoctial months.

1 2.52 McIlroy and Slatyer Method

The modified Penman, Mc Ilroy and other equations represent more realistic models of the transpiring plants in the atmosphere than does the original Penman type. The McIlroy version of combination method equation is:

$$E = \frac{S}{S+\gamma} \times \frac{(R-G)}{L} + \frac{h}{L} (D-D_o)$$

where S is the slope of the saturation vapor pressure curve for water vapor

at the mean wet-bulb temperature of the two levels,

$$\gamma = \frac{C_p}{L},$$

C_p is the specific heat of air at constant pressure, R is the net radiation flux received at the surface, G is the heat storage, L is the latent heat of vaporization, h is the transfer coefficient, D_o and D are the wet-bulb depressions at the water surface and height respectively.

$\frac{h}{L}$ is the atmospheric conductance, the value of which depends on both the aerodynamic roughness of the evaporating surface and the turbulent transfer characteristics of the atmosphere.

Under conditions when the surface is saturated, D_o approaches D , and estimates of evaporation are virtually the same as those derived by Penman (1948). McIlroy (1968) calls this the potential evapotranspiration and it is given by:

$$E \text{ (pot)} = \frac{S}{S+\gamma} \times \frac{(R-G)}{L} + \frac{hD}{L}.$$

An advantage of this method is that it has potential application to surfaces which are not saturated, and McIlroy (1968) gives the following expression which avoids the difficult measurement of D_o :

$$E = \frac{E \text{ (pot)}}{1 + \frac{\gamma}{s+\gamma} \times \frac{h}{h_i}}$$

where h_i is analogous to h but is applicable to the molecular diffusion of water vapor through stomata, or the dry top layer of soil as the case may be, and can be related to the soil moisture content.

1 2.53 Priestly and Taylor Model

Priestly and Taylor used the equation:

$$E = \frac{\alpha}{L} \frac{(S)}{S+\gamma} (R_N - G)$$

for estimation of evapotranspiration over the surfaces where surface resistance was expected to be negligibly small and E_o , (defined previously), was expected to be equal to the actual evapotranspiration rate. They used both terrestrial and oceanic data to determine the coefficient α for their equation, where the energy flux density terms were 24 hour integrals and S was calculated from the mean surface temperature. The best value of α was found to be 1.26. This estimate of α is the overall mean of land and water surface. They conclude that their values of α obtained by their method are intended primarily for apportioning the net radiation over substantially saturated land area.

1 2.54 McNaughton and Black Method

Another form of combination method is that used by McNaughton and Black (1971) for an experimental Douglas fir forest in British Columbia, Canada. They used the Van Bavel (1966) model, which can be written as

$$E_o = \frac{1}{L} \times \frac{S}{S+\gamma} \times (R_N - G - M) + \frac{\rho C_p (e_z^* - e_z)}{(S+\gamma) r_a L}$$

where E_o is the free evaporation rate, e_z^* is the saturation water vapor pressure at height Z , r_a is the aerodynamic diffusion resistance at height Z . It is assumed that r_a is equal to U_z / U_*^2 where U_z is the wind velocity at height Z , and U_* is the friction velocity.

Monteith (1965) introduced the effect of plant stomatal diffusive resistance to vapor flow by considering the vegetative canopy as a single extensive isothermal leaf. Following a similar procedure to that of Penman (1948), Monteith derived the expression for transpiration

$$E = \frac{E_o}{1 + \frac{(\gamma)}{S+\gamma} \frac{r_s}{r_a}}$$

where the surface resistance, r_s , is formally identified as the resistance of all the stomata of the leaves of the canopy acting in parallel.

For some forest situations, total evapotranspiration can be considered as entirely transpiration with only small error when intercepted water is not present since forest soil evaporation has been found to be small by many workers (e.g. Rutler, 1966).

Perhaps a realistic estimate of the influence of intercepted water can be obtained by comparison of the McNaughton and Black model with Priestly and Taylor (1972).

Measured evapotranspiration rates from the University of British Columbia forest site were plotted against $\frac{1}{L} \frac{(S)}{S+\gamma} (R_N - G)$. Neglecting the two days of rainfall in July, the slope α of the least-square line through the data was found to be 1.05. Alternatively stated, the value of α , to force a straight line with slope equal 1 through the data mass for measured evapotranspiration versus $\frac{\alpha}{L} \left(\frac{S}{S+\gamma} \right) (R_N - H)$ was calculated to be 1.05.

An estimate of the importance of interception losses by the forest was made by McNaughton and Black (1970). They considered firstly gross interception loss (GIL), the amount of precipitation onto the forest that is caught by the canopy and evaporates without reaching the ground. Then net interception loss was defined as the difference between gross interception loss and the reduction in transpiration caused by the presence of the intercepted water. According to this structure of analysis, McNaughton and Black (1970) found that only 17% of the gross loss can be considered to be net loss. In other words, GIL substantially reduces transpiration.

The best potential evapotranspiration relationship that can be suggested from their study is

$$PE = \frac{1.05}{L} \frac{(S)}{S+Y} (R_N - G) + 0.17 GIL$$

1. 2.55 Modified Linacre Method

A semi-empirical method for estimation of evapotranspiration is derived by Linacre (1967) through the combination of Penman's method (see Penman's method described earlier) and solar radiation equations. The ratio LE/Q_s can be deduced by means of two basic equations: The first is an analogue to Penman's formula for lake evaporation; the second concerns the net radiation flux, Q_n , expressed in terms of its components (see the radiation section).

A forest canopy may be considered as impeding the loss of water by means of two resistances. The canopy resistance (analogous to crop resistance, Linacre, 1967), r_c , which is a function of canopy structures and its

properties. The second factor is aerodynamic resistance, r_a , which is a function of canopy - atmosphere interface. The combined equation is (Linacre, 1967)

$$LE = \frac{\Delta Q_n + C_p \cdot \rho \cdot \frac{S}{r_a}}{\Delta + \gamma + \gamma \frac{r_c}{r_a}} \quad (1)$$

in which Q_n is the difference between downwards and upwards radiation fluxes; C_p is the specific heat of air at constant pressure; ρ is the air density; S is saturation deficit, and Δ is the change of water vapor pressure with temperature in ambient conditions. The psychrometric constant, γ , has a value of about 0.5 mm Hg per degree of centigrade. Between 0° and 40 °C, the product $C_p \cdot \rho$ from 0.31×10^{-3} to 0.27×10^{-3} cal. cm⁻³ (Linacre, 1967). The saturation deficit, S , is defined as

$$S = (1 - RH)e_s \quad (2)$$

expressed in mm Hg, in which RH is the ambient relative humidity, and e_s is the saturation water-vapor pressure at the ambient temperature (in mm Hg).

The net radiation flux, Q_n , is

$$Q_n = (1 - \alpha) Q_s - |Q_{sL}| \quad (3)$$

in which α is albedo, Q_s is the total short-wave radiation, and Q_{nL} is the net long-wave radiation, which is given by equation

$$Q_{nL} = (-0.245 + 0.158 \times 10^{-10} T_k^4) (0.2 + 0.8 \frac{n}{N}) \quad (4)$$

which can be approximated by

$$Q_{nL} = -32 \times 10^{-5} (1 + 4 \frac{n}{N}) (100 - T) \quad (5)$$

in cal. cm⁻². min.⁻¹. Linacre (1967) has shown a good agreement between equations (4) and (5).

Using radiation equations in equation (1), one obtains

$$\frac{LE}{Q_s} = \frac{-|-32 \times 10^{-5} \Delta (1 + 4 \frac{n}{N}) (100 - T)| + 3 \times 10^{-4} \frac{(1 - RH) e_s}{r_a}}{Q_s} + \Delta (1 - \alpha) \quad (6)$$

$$\Delta + 0.5 (1 + \frac{r_c}{r_a})$$

Because Q_s on the right side of equation (6) divides only part of the numerator, and that part is only a difference between terms, Q_s need not be known accurately to evaluate the ratio LE/Q_s . Linacre (1967) replaced Q_s in the numerator by an approximation, based on the notion that the ambient temperature depends on the solar radiation flux and hence may be correlated with it. Of course, this is not exactly the case, because advection and thermal storage in the ground also affect the ambient temperature. This has been shown by other scientists such as McIlroy and Angus 1964, Impens, 1963 and Aslyng, 1960, 1966.

Linacre's approximation is

$$Q_s = 0.015 T - 0.026 \text{ cal. cm}^{-2} \cdot \text{min.}^{-1} \quad (7)$$

The correlation coefficients for all data processed (several areas throughout world) by Linacre (1967) is 0.88. The correlation coefficient is for Aspendale, Australia, Ghent, Belgium, and Copenhagen, Denmark. For greater simplicity, equation (7) may be replaced by

$$Q_s = 0.02T.$$

Another approximation was also made by replacing Δ by a proportionality, shown valid over a temperature range of 10 °C to 30 °C

$$\Delta = 0.06 T \text{ mm Hg per } ^\circ\text{C} \quad (8)$$

The justification for this approximation again lies in the form of equation (6): Δ affects only a difference between factors in the numerator, and also appears both in numerator and denominator, so errors in Δ are

$$\frac{LE}{Q_s} = \frac{6 \times 10^{-2} T (1-\alpha) + 15 \times 10^{-3} \frac{(1-RH)e_s}{T r_a} - 96 \times 10^{-5} (1 + 4 \frac{n}{N}) (100-T)}{6 \times 10^{-2} T + 0.5 (1 + \frac{r_c}{r_a})} \quad (9)$$

According to equation (9) factors governing LE/Q_s are: temperature, saturation deficit, relative humidity, a cloudiness term, $(\frac{n}{N})$, and the canopy itself, which determines r_a and r_c as well as albedo. Most of these factors could be measured and/or estimated by remote sensing techniques, either directly or indirectly, and consequently the amount of evapotranspiration may be estimated.

In this method r_c and r_a may be analogous to r_s and r_a in McNaughton and Black's model.

1 2.60 Empirical Methods

A large number of empirical methods are used for estimating or predicting evapotranspiration when (a) inadequate meteorological and soil-crop data are available to apply complete rational equations based on the physical process involved, or (b) the absolute accuracy of the data needed may be adequate using simple empirical equations that require much less time and effort to solve, and or (c) complete rational equations often require greater technical ability and experience in meteorology, physics and forestry than many users of evapotranspiration data have or can justify attaining.

Most of the empirical methods use temperature as one of the major variables. The higher the air temperature, the greater the capacity of the air to hold moisture and the greater the evaporation that will occur. To illustrate, at 0°F, the atmosphere at sea level will hold 0.9 grams of water per kilogram of air, at 50°F, it will hold 8.0 grams/kilogram; and at 100°F, it will hold 44.0 grams per kilogram. (Water Res. Bull., No. 73-1, 1974.)

I 2.61 Thornthwaite Method

Thornthwaite, 1948, developed the equation

$$E_t = 1.6 (10 t/l)^a$$

Where E_t is the potential evapotranspiration for a 30-day month, t is the mean air temperature (°C) for that period, l is a heat index which is the sum of 12 monthly indices,

$$l = (t/5)^{1.514}$$

and a is a cubic function of l .

Thornthwaite and Mather (1954) claim that mean temperature can serve as an index of evapotranspiration because there is a fixed relation between the net radiation used for heating and that used for evaporation when conditions exist to achieve the potential rate.

I 2.62 Blaney-Criddle Method

Blaney and Criddle (1950) developed the equation

$$e = k (tp) (114-h)$$

where e is monthly evaporation in inches, k is a monthly coefficient, t is the mean monthly temperature (°F), p is the monthly percentage of day-time hours in the year, and h is the mean monthly relative humidity in percent.

This method has been used in most of the United States, and in many foreign countries. It has been found to be satisfactory for water consumptive use where measured water loss data are not available.

Phelan proposed a modification of the Blaney-Criddle formula as given by Quackenbush and Phelan (1965) where $k_c k_t$ is substituted for the k in the formula. The coefficient k_c is a strict empirical constant. Its values for each month are determined experimentally. Values of R_t are given by the equation

$$k_t = 0.0173t - 0.314 .$$

1 2.63 Hargreaves Method

Hargreaves (1956) developed the equation

$$E_v = 0.38 (1 - 0.1H_n) D (T - 32)$$

Where E_v is Class A pan evaporation in inches, D is a monthly daytime coefficient defined as the ratio of the daylength for the month to 12 hours (the values of D are equal to the values of P in the Blaney-Criddle formula multiplied by 0.12, H_n is the monthly relative humidity at noon (humidity at 1:00 P.M. can also be used satisfactorily), and T is the mean monthly temperature in °F.

One of the problems of using Hargreaves model is to be found in the difficulties encountered in locating published data for noon humidity. Chindasnguan (1966) found that humidity at noon is approximately the same as the daytime average (11 A.M. and 5 P.M.). Al-Barrak (1964) developed a formula for converting mean humidity for a 24-hour period to mean humidity at noon. This formula has been compared with data from Thailand and Columbia and somewhat modified. The revised formula can be written as follows:

$$H_n = 1 + 0.4 H + 0.005 H^2$$

in which H is mean humidity for a 24 hour period. Either daily values or monthly averages may be converted.

Mathison (1963) plotted relative humidity against temperature differences. The line of best fit can be expressed by the equation:

$$H_n = 113 = 2.5 (\Delta T)$$

in which ΔT is the difference between the mean maximum and minimum temperature in °F.

$$\Delta T = T (\text{max.}) - T (\text{min.}).$$

All the formulas in this method are based on 60 miles of wind movement per day. Evaporation increases or decreases about 9% with each 30 miles per day increase or decrease in the wind.

This method is also based upon conditions of approximately 90% sunshine. The percent sunshine could be calculated or derived from cloud cover tables. In the present context, space imagery, especially data acquired from, meteorological satellites, might prove to be very useful for estimating cloud cover. Palayasoot (1965) developed the following formula

$$S = 74.5 + 9.5C - 2.0C^2$$

in which S is the percent sunshine and C is cloud cover, on a scale of 0-8.

This method's formula is based on data from locations with an average elevation of 500 feet. Since evaporation increases with elevation, the formula can be corrected by increasing the calculated values of 1.0 percent for each 300 feet increase in elevation or by 3.0 percent for each 1000 feet increase.

I 2.64 Christiansen Method

Christiansen and his graduate students at Utah State University (1966) developed a set of formulas for estimation of evapotranspiration. The approach was both rational and empirical. The basic formula developed can be written

$$E = K R C$$

in which E is the evaporation or evapotranspiration, K is a dimensionless constant, determined from an analysis of many data, R is the theoretical solar radiation reaching the earth's outer atmosphere, expressed in the same units as E, and C is a dimensionless empirical coefficient, which is the product of any number of subcoefficients each expressing the effect of given climatic or other factors. Thus,

$$C = C_T \cdot C_H \cdot C_W \cdot C_S \cdot C_E \text{ etc.}$$

where T, H, W, S, and E are mean monthly values of temperature, humidity, wind, sunshine, and elevation. The coefficients for these climatic factors were developed from an analysis of many data. In theory each coefficient represents the effect of a single factor considering all other factors constant.

Each coefficient has generally been expressed as a second degree equation of the form

$$C_X = A + BX + CX^2$$

except where the data suggested a different form of equation. In this equation X represents a dimensionless parameter of a climatic or other factor which is the ratio of the climatic factor to a standard value of the factor that forces the coefficient C_X to be unity. For example, the wind coefficients

in the Christiansen-Mehta formula (1965) can be expressed by the equation

$$C_w = 0.790 + 0.222 (W/W_0) - 0.012 (W/W_0)^2$$

in which W is the mean monthly wind velocity in any desired unit, and W_0 is the standard value of the wind velocity for which the value of the coefficient C_w is 1.0.

To obtain an estimate of the pan evaporation or evapotranspiration for a given month, mean values of each factor are tabulated. From the graphs, or tables, values of the $C_{(x)}$ coefficients, or logarithms of the coefficients, are next determined. The computation is then simply a matter of multiplying coefficients, or adding logarithms and taking the antilogs. Anyone using this formula must exercise good judgment in the selection of k values in order to obtain reliable values of E .

1 2.65 Jensen and Haise Method

The Jensen and Haise (1963) method uses total short-wave solar radiation (R_s), (expressed in inches of evaporation equivalent) as its climatic factor and a dimensionless crop coefficient (ET/R_s) to reflect the effect of crop type and stage of growth, as well as climatic factors not accounted for by solar radiation. Thus:

$$ET_p = (ET/R_s) R_s$$

In addition, the equation

$$ET_p = (0.014 T - 0.37) R_s$$

is presented, where ET_p is potential evapotranspiration in inches, T is mean daily temperature in $^{\circ}F$, and R_s is total solar radiation in inches of evaporation equivalent.

The linear temperature correction factor was derived by plotting ET/RS versus T for selected crops in which evaporating and transpiring surfaces were not limiting the vaporization of the water.

Somewhat similar equations have been proposed by Turc (1961) for computing evapotranspiration. For humid areas (average relative humidity greater than or equal to 50 percent), he proposes the equation

$$ET_p = 0.013 \frac{T}{T + 15} (R_s + 50)$$

and for areas with less than 50 percent humidity the following:

$$ET_p = 0.013 \frac{T}{T + 15} (R_s + 50) \left(1 + \frac{50 - RH}{70}\right),$$

where ET_p is potential evapotranspiration in millimeters per day, T is mean daily temperature in degrees centigrade, R_s is solar radiation in Langleys, (calories per squared centimeter per minute) and RH is relative humidity in percent. Turc does not offer any crop factors and states that they should only be applied with prudence.

For areas where incident radiation values are not available, Jensen and Haise (1963) gave two equations

$$R_s = R_{so} (0.35 + 0.61S)$$

attributed to Fritz and McDonald (1949) and

$$R_s = R_{so} (1 - 0.1 \ln (1 - k))$$

from Budyko (1958).

In these equations, R_{so} is the solar radiation on cloudless days, S is the possible sunshine percentage, expressed decimally, k is the mean annual coefficient, varying with latitude from 0.35 at the equator, to 0.32 for latitudes of 2.5° to 35° north, then increasing to 0.40 for latitude 60°

north, and n is the cloud cover in tenths (scale 0 to 10).

The solar radiation methods discussed above might be termed semi-empirical approaches. They are essentially energy balance methods, being based on the fact that the principal source of energy for evapotranspiration is incoming solar radiation. Empirically derived factors to account for other climatic effects and the effect of type and phenological phase of vegetation are applied to reduce the total incoming solar radiation to evapotranspiration. The Jensen and Haise (1963) equation is rearranged by David and Robb (1966) to

$$ET = (1 - r) R_s - R_{et} - A - G,$$

where ET is evapotranspiration, r is reflectance or albedo, R_s is total shortwave solar radiation, R_{et} is effective thermal radiation, A is the sensible heat flux to the air (negative for flux from the air), and G is the sensible heat flux to the ground (negative for flux from the ground).

1. 2.66 Turc's Model

Turc studied 254 natural watersheds throughout the world and tested the predicted consumptive use by inserting its value in

$$RO = P - CU$$

where RO is runoff, P is precipitation, and CU is consumptive use. A comparison was then made between calculated RO with measured RO . The predictions gave very good agreement between the two values. (Lewis and Burgy 1966).

Turc uses the equation

$$C_u = \frac{P}{\left(0.9 + \frac{P^2}{L^2}\right)^{\frac{1}{2}}}$$

in his method where $L = 300 + 25T + 0.05 T^3$. T is the mean annual temperature in °C, p is annual precipitation in millimeters, and C_u is consumptive use in millimeters.

Pike (1964) has indicated that Turc's equation may be written in terms of a ratio of actual consumptive use to potential evapotranspiration with the substitution of unity for the constant, 0.9. In this form Turc's equation becomes

$$\frac{C_u}{L} = \frac{P}{(P^2 + L^2)^{\frac{1}{2}}}$$

where the terms are previously defined (Lewis and Burgy 1966). In this equation Turc's L is a measure of annual evapotranspiration. Pike demonstrated that his equation fitted characteristics of certain watersheds in Malawi when Penman's E_o (potential evapotranspiration) was substituted for Turc's L . Lewis and Burgy (1966) showed a good agreement between the measured consumptive use calculated by the Turc and Pike methods.

1. 3.00 Radiation Theory Applied to Evapotranspiration Modeling

All bodies radiate energy, the intensity of the radiation being a function of the temperature of the radiating body; moreover, the spectral distribution of the radiation is also a function of the temperature of the radiating body. Generally speaking, the higher the temperature, the greater the intensity of the total radiation emitted and the shorter the

wavelength of the maximum intensity. (Corps of Engineers, Portland, Oregon 1956.) The spectral distribution of the energy of a radiating black body is given by Planck's Law,

$$E_{\lambda} = \frac{C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)} \quad (1)$$

where E_{λ} is the intensity of emitted radiation of wavelength λ , T is the temperature of the radiating body, and C_1 and C_2 are constants.

The wavelength of maximum intensity of radiation can be determined from for any given temperature. E_{λ} is zero for $\lambda=0$ and for $\lambda=\infty$; for some intermediate value of λ , E_{λ} has its maximum value. Wien's law determines this maximum value, differentiating the Plank's equation and equating it to zero gives

$$\lambda_m T = \text{constant} \quad (2)$$

where λ_m is the wavelength at which E_{λ} is maximum. The value of the constant is usually taken as 2940 for wavelengths expressed in microns and temperatures in degrees Kelvin. Thus the wavelengths of maximum intensity are 0.49 μ and 10.8 μ for temperatures of 6000^{ok} (sun) and 273^{ok} respectively.

The total energy emitted in all wavelengths (per unit time and area) by a black body is determined by integrating equation (1): Thus the total radiation in all wavelengths, E , from a black body at a temperature T is,

$$E = \sigma T^4$$

where

$$\sigma = \int_0^{\infty} \frac{C_1}{(\lambda T)^5 (e^{C_2/\lambda T} - 1)} d(\lambda T) \quad (3)$$

(Corps of Engineers, U.S. Army, Portland, Oregon, 1956.) Equation (3) is known as Stefan Boltzman's law and was Stefan Boltzman's Constant,

$$Q = 0.826 \times 10^{-10} \text{ (ly/min)/} (^{\circ}\text{K})^{-4} \quad (4)$$

For a radiating body other than a black body, its radiation relative to the radiation of a black body is expressed by a ratio known as its emissivity.

Only a very small portion of the entire electromagnetic spectrum is involved in evapotranspiration. This radiation is divided into two general categories: shortwave (solar) and longwave (terrestrial). Shortwave radiation is included in the range from about 0.15 to 4μ which includes the visible spectrum (0.36 to 0.76μ). It has its maximum intensity in the visible spectrum at about 0.5μ , and also extends into the ultra violet and the infrared. Terrestrial radiation is generally included in the range 3 to 80μ ; it has its maximum intensity in the infrared at approximately 11μ . (Corps of Eng. Portland, Oregon 1956.)

Of the tremendous quantity of radiant energy emitted by the sun, only a very small portion is intercepted by the earth and its atmosphere. This small portion is the ultimate source of the earth's energy. This amount of incident radiation is known as the solar constant which is defined as the intensity of solar radiation received on a unit area of a plane normal to the incident radiation at the outer limit of the earth's atmosphere with the earth at its mean distance from the sun. The value of the solar constant is generally taken to be 1.94 Langleys per minute which is based on the 1913 Smithsonian standard scale. Recently there has been evidence that this value is too low and a value of 2.00 ly/min has been offered (Miller, 1951).

The portion of the solar radiation which actually reaches the earth's surface depends upon the transparency of the atmosphere. Some of the incident solar radiation is reflected, some scattered, and some absorbed by the atmosphere. In the absence of clouds these amounts are relatively small and quite constant. The variations that occur are chiefly a result of variations in the amount of water vapor and dust in the air. The atmospheric transmission coefficient varies from about 80 percent at the time of the winter solstice to about 85 percent at the time of the summer solstice. Atmospheric transmission coefficients are based on the total insulation received at the earth's surface and include both the direct and diffused radiation.

By far the largest variation (in the portion of solar radiation transmitted by the atmosphere) are caused by clouds. The transmitted radiation varies with type, height, density, and amount of clouds. The quantitative consideration will be discussed later. Since clouds are such a powerful controlling factor in radiative heat exchange, other minor factors such as humidity of the air are often ignored.

Similar to the cloud effects, the forest canopy exerts a powerful controlling influence on net allwave radiation exchange in evapotranspiration. However, the forest canopy has a different effect than that of clouds, particularly with respect to shortwave radiation. While both the clouds and trees restrict the transmission of insulation, clouds are highly reflective, while the forest canopy absorbs much of the insulation. Consequently, the forest canopy tends to be warmed and in turn gives up a portion of the energy for evapotranspiration.

I 3.01 Definition of Albedo

The reflection or albedo is the ratio of reflected to the incident radiation, usually expressed as a percentage. Table 1.1 gives albedos for the total range of solar radiation and in some cases for the visible electromagnetic range only. The figures given in this table illustrate what can be observed directly from an airplane. The sea appears darkest, relative to white strips of surf and sand dunes. Over land, woods show up darker than fields, and snow covered areas are light. One can see here how the absorption capacity for incident solar radiation varies and how this affects the whole heat economy and therefore evaporation and evapotranspiration. Albedo is influenced not only by the nature of a surface, but also by its moisture content at any time, i.e., wet surfaces appear darker than dry surfaces.

I 3.02 Determination of Net Radiation Flux

The net radiation flux Q_n , may be calculated from the equation

$$Q_n = (1-\alpha) |Q_s - Q_{nL}| \quad (5)$$

where α is albedo, Q_s is the total flux of shortwave radiation from the sun and the sky, and Q_{nL} is the net upward flux of longwave radiation computed as follows:

$$Q_{nL}^* = Q_{Ld} - Q_{Lu} \quad (6)$$

$$Q_{Ld} = 0.971 \times 10^{-10} T_k^4 - 0.245 \text{ (cal. cm.}^{-2} \text{ min.}^{-1}\text{)} \quad (7)$$

TABLE 1.1

<u>Stand</u>	<u>Albedo Percent</u>	<u>Source</u>
Fresh snow cover	75-95	Geiger
Dense cloud cover	60-95	"
Old snow cover	40-70	"
Clean firn snow	50-65	"
Light sand dunes, surf	30-46	"
Clean glacier ice	20-50	"
Sandy soil	15-40	"
Meadow and fields	12-30	"
Meadow, low grass	15-25*	Smithsonian table
Field, plowed, dry	20-25*	"
Densely built-up area	15-25	Geiger
Woods	5-20	"
Dark cultivated soil	7-10	"
Douglas-fir	13-14	Avery
Pine	14	Brooks
Conifers	10-15	Budyko
Deciduous forest, fall	15*	Krinov
Deciduous forest, summer	10*	"
Coniferous forest, summer	8*	"
Coniferous forest, winter	3*	"
Meadow dry grass	10*	"
Field Crops, ripe	15*	"
Spruce	8-9	Baumgartner

Table 1.1 (cont.)

Albedo, PercentSource

<u>Stand</u>		
Earth roads	3*	Krinov
Black top roads	8*	Sewing Handbook
" " "	9*	Krinov
Concrete road	35*	"
Buildings	9*	"
Mountain tops, bare	24*	"
Clay soil dry	15*	Sewing Handbook
Clay soil wet	7.5*	"

*visual albedo

$$Q_{Lu} = 0.813 \times 10^{-10} T_k^4 \quad (\text{cal. cm}^{-2} \cdot \text{min}^{-1}) \quad (8)$$

where Q_{nL}^* is the net flux of longwave radiation in cloudless conditions, Q_{Ld} is the downward flux of longwave radiation from a clear sky (derived from the formula of Swinbank, 1963, (T_k) is the ambient temperature in degrees of Kelvin and Q_{Lu} is the upward flux of longwave radiation from a surface with unit emissivity (Linacre, 1968). Then

$$Q_{nL} = Q_{nL}^* [b + (1-b) \frac{n}{N}] \quad (9)$$

where there are n hours of actual sunshine in a daylength of N hours. The term b has been taken to be either 0.10 (penman, 1948), 0.20 (Kramer, 1957), 0.24 (Impens, 1963), or 0.30 (Fitzpatrick and Stern, 1965); a value of 0.20 may be adopted as a compromise (Linacre, 1968). Combining these equations

$$Q_{nL} = (-0.245 + 0.158 \times 10^{-10} T_k^4) (0.2 - 0.8 \frac{n}{N}) \text{ in cal. cm}^{-2} \cdot \text{min}^{-1}. \quad (10)$$

$$Q_n = (1-\alpha) Q_s - |(-0.245 + 0.158 \times 10^{-10} T_k^4) (0.2 + 0.8 \frac{n}{N})| \quad (11)$$

The value of Q_s is estimated by Linacre (1967) by means of the modified Angstrom equation

$$Q_s = Q_A \left(c + d \frac{n}{N} \right) \quad (12)$$

where Q_A is the value of Q_s above the atmosphere c and d are empirical constants, n and N are as previously defined. n is measured and values of N depend on the latitude and time of year, and are available in tables (Smithsonian Institution). The same applies to values of extra-terrestrial radiation intensity, Q_A . The values of n may be gained through remote sensing techniques. Normally, however, is measured in the field. Table 1.2

Table 1.2 Published values of the Factors c and d in equation (11)

Source (1)	Location (2)	Latitude (3)	Period of Means (4)	c (5)	d (6)	ctd (7)	\bar{c} (8)	\bar{d} (9)	$\overline{c \cdot d}$ (10)	Latitude (11)
Black et al (1954) Monteith (1966) Penman (1948) Baier and Robertson(1963) Black et al. (1954) Van Wijk (1963) " " "	Stockholm, Fairbanks Lerwick Rothamsted, U.K. Canada Kew, U.K. Gembloux Versailles	59.65°N 60°N 52°N 52°N 51°N 51°N 49°N	month day month day month month month	0.22 0.23 0.18 0.25 0.19 0.15 0.23	0.52 0.56 0.55 0.62 0.57 0.54 0.50	0.74 0.79 0.73 0.87 0.76 0.69 0.73	0.21	0.55	0.76	54°
Tanner and Pelton(1960) de Villele (1965) de Vries (1958) Damagnez (1963) Prescott, (1940) Black et al (1954) Page (1961)	Wisconsin El Aouina Deniliquin Tunisia Canberra Dry Creek Capetown	43°N 37°N 36°S 35°N 35°S 35°S 34°S	- 10 days day - month month month	0.18 0.28 0.27 0.16 0.25 0.30 0.20	0.55 0.43 0.54 0.59 0.54 0.50 0.59	0.73 0.71 0.81 0.75 0.79 0.80 0.79				
Glover (1958) Yada (1959) Glover (1958) " " Page (1961) Smith (1964)	Durban Delhi Pretoria Windhoek Tananarive Jamaica	30°S 29°N 26°S 23°S 19°S 18°N	day week day day month day	0.25 0.31 0.25 0.26 0.30 0.31	0.50 0.46 0.50 0.52 0.48 0.49	0.76 0.77 0.75 0.78 0.78 0.80	0.28	0.49	0.77	24°
Fitzpatrick (1967) Cackett (1964) Page (1961) Yada (1959) Davies (1965) Smith (1964) Stanhill (1963)	Kimberley Central Africa Dakar Madras Kano Trinidad Benin City ^a	16°S 15°S 15°N 13°N 12°N 11°N 7°N	day - month week month day week	0.33 0.32 0.10 0.31 0.26 0.27 0.26	0.43 0.47 0.70 0.49 0.54 0.49 0.38	0.76 0.79 0.80 0.80 0.80 0.76 0.64				
Davies (1965) Black et al (1954) Page (1961) " " Glover (1958) Page (1961) Rijks (1964)	Accra Batavia etc. Leopoldville Singapore Kabete, Kenya Stanleyville Kampala	6°N 6°S 4°S 1°N 1°S 1°N 0°	month month month month 10 days month day	0.30 0.29 0.21 0.21 0.24 0.28 0.24	0.37 0.29 0.52 0.48 0.59 0.40 0.46	0.67 0.58 0.73 0.69 0.83 0.68 0.70	0.25	0.44	0.69	3°
Hounam (1963) Davies (1965) Black et al (1954) Page (1961) Turc (1961)	Australia West Africa general tropics general	12-43°S 5-15°N - - -	month month month month month	0.26 0.19 0.23 0.23 0.18	0.50 0.60 0.48 0.52 0.62					
Mean Values				0.245	0.507	0.752				

^aDavies (1965) gave 0.28 and 0.33 for c and d respectively

SOURCE: Linacre, 1968

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shows the values for c and d. Linacre's equation is not exact because it doesn't allow for the varying importance of cloudiness at different times of the day.

Equation (11) has been found satisfactory by several investigators (Black, 1956, Abdel-Aziz, 1964, and Linacre, 1967). Stanhill (1965) found the estimated weekly values of Q_s were within 6% of measured values, which is comparable with the errors inherent in actual measurements.

References

For reference see section 2.500b.

**APPENDIX II: EVALUATION OF CURRENT MODELS FOR EVAPOTRANSPIRATION
ESTIMATION**

Siamak Khorram

APPENDIX II EVALUATION OF CURRENT MODELS FOR EVAPOTRANSPIRATION ESTIMATION

II 1.0 INTRODUCTION

The problem of obtaining an estimate of evaporation from an area is a very difficult task in most instances and is often simplified by using representative point estimates in catchments (watersheds) or sub-catchments. The estimation of areal evapotranspiration is more difficult because of diversification of evaporating surfaces in most catchments, and the consequent need for a proportionally large number of evaporation measuring points, which are often expensive to install and maintain.

Approximations and over-simplifications with regard to procedures of data are often made. For example, vapor pressure of the bulk air is sometimes substituted for surface vapor pressure, with considerable loss in reliability; net radiation may be estimated from sunshine or even cloudiness and air temperature, while the advection term, which can be quite significant in watershed evapotranspiration, is neglected in most methods.

The use of remote sensing techniques in cost-effective combination with a limited number of appropriate ground sensors, could solve some of the above-mentioned problems. This evaluation of current methods will help provide a baseline against which to judge the applicability of the various model types to each information resolution level of our proposed remote sensing-aided evapotranspiration estimation system.

Most of the computational methods are based on some form of meteorological observation, but they are "indirect" in the sense that evapotranspiration is computed from other meteorological elements. Practically all such methods make assumptions and must therefore be calibrated against a more

reliable procedure.

II 2.0 WATER BALANCE

The water balance method may be classified as direct and considered as a possible absolute standard, but, unfortunately, the degree of accuracy is rather low. The large error often involved in measuring the other variables is then built-in to the residual term - evapotranspiration. This method has the considerable advantage that it integrates all spatial variations of evapotranspiration over a catchment without the need to know details in these variations. It can also be used on any scale ranging from continental land mass and hydrological catchment down to point observation.

Application of this method ordinarily involves setting up an expensive ground network to measure rainfall, runoff, underground drainage, and soil moisture changes. However underground drainage measurements are difficult to make. Soil moisture presents difficulties unless the water balance reporting time interval is selected to allow assumption of zero change in soil water storage over the period. Rainfall is sometimes assumed to be accurately observable, and estimated for the watershed, a situation unlikely in most cases.

Since the accuracy of the estimate of catchment evapotranspiration depends on the accuracy of the other terms in the water balance equation and in view of the probable inaccuracies in rainfall, runoff, deep drainage, and soil moisture measurement, reliable evapotranspiration values are not likely in most circumstances.

The primary use of this model in the remote sensing-aided system

will be to provide a final basin-estimated water input versus loss equation. The difference will represent estimated water yield for the watershed or sub-watershed of interest. Predicted precipitation, snow water content loss, evapotranspiration, water loss and subsurface flow water loss based on the remote sensing-aided approach described earlier will be substituted into the water balance equation to give water yield.

11 3.0 Methods Using Energy Balance

The energy balance method has repeatedly been shown to be a reliable and conservative method of determining evapotranspiration for periods of time as short as one hour, Jensen (1966).

Net radiation is the key quantity in the energy-balance equation, and the degree of accuracy obtainable by the method depends mainly on the accuracy with which this can be measured. Although national networks for the measurement of total radiation have expanded steadily in recent years, the measurement of net radiation has not followed at the same rate. Two good reasons for this are the greater fragility of the equipment and the difficulty of determining a representative surface.

Empirical relationships have been developed for the estimation of total radiation, the most common using a cloud cover or sunshine correction to the radiation at the top of the atmosphere (solar constant). The relationships are usually easy to apply to catchments where climatological data are available, and estimates can be made of the areal variation of parameters; but the degree of accuracy is not high. The use of remote sensing techniques might improve considerable the accuracy of the radiation measurements.

In the energy-balance method the height at which observations are made above the surface is rather critical, as the equality assumption for the turbulent transfer coefficients in the energy-balance equation is not always justified beyond a certain distance from the surface. The difficulty increases with geometrically mixed stands of vegetation where, in addition to great surface irregularity, there are real spatial differences in evapotranspiration rates.

Under these conditions a sensor will be more influenced by heat and vapor sources in its immediate neighborhood and not by more distant sources which may be transpiring at a different rate. By raising the height of observation point the sensor will be influenced by a wider area of heat or vapor source and, as a result of turbulent mixing, an average value from the area will be sensed. The discussion on advection is relevant here, and it will be noted that only a small increase in height means that the sensor is looking a considerably further distance upwind. It may be concluded, based on stability and advection variation, that the energy-balance method is more appropriate in situations where the vegetation is reasonably homogeneous.

A suitable observational height over a fairly homogeneous forest might be two or three meters above the canopy with the second level some eight to ten meters above it. In this case the remote sensing-aided evapotranspiration system would provide estimates of the needed parameters at the various heights required by the energy balance model. These estimates would be obtained through the spatial and vertical canopy transformation functions described in Section 2.322b, particularly those of Section 2.523b

Similar parameter estimates would be made for heights required by other evapotranspiration models discussed in Appendix II.

A combination of energy-balance and Bowen ratio seems the most appropriate form of application of energy-balance for forest evapotranspiration estimation, although estimation of the Bowen ratio is a very difficult problem. Tanner (1963) has shown the practical advantage of determining the Bowen ratio by means of gradient measurements of temperature and humidity as those are not dependent on wind profile shape and generally change in similar fashion with changes in wind structure. This, of course, neglects the effect of advected energy.

Generally speaking, energy-balance techniques for estimating evapotranspiration have proven reasonably more accurate in the more humid regions of the country. It seems that this method is appropriate to be applied in the second level of information resolution in our proposed remote sensing-aided evapotranspiration estimation system. The results of application of the energy-balance method to a forest by McNaughton and Black (1972) were found to show a consistent pattern with two distinctive features that differentiate them from typical balances for low height agricultural crops. Short fluctuations in radiation did not produce corresponding proportional changes in the latent heat flux. This pattern may be contrasted with, for example, an energy balance of irrigated alfalfa-brome grass on a partly cloudy day as measured by Tanner and Pelton (1960) where changes in net radiation and latent heat flux are strongly coupled. Secondly, peak evapotranspiration rates in the McNaughton and Black model occurred two or three hours after solar noon. Gay (1972) has reported a near identical

pattern for a clear July day energy balance of a taller Douglas-fir forest at Cedar River, Washington. Fritschen (1973) has made lysimetric measurements of evapotranspiration from a single Douglas-fir tree in early May 1972 on the same site as used by Gay. His results also show that the daily evapotranspiration maxima occur several hours after the net radiation maxima. These results show that forest evapotranspiration is not directly driven by net radiation in accordance with the approximation of Monteith's equation for rough surfaces.

II 4.0 Aerodynamic Methods

Aerodynamic techniques assume similarity in the mechanisms of the flux of momentum, heat, and water vapor. This assumption is not always justified and is almost always troublesome. It can be readily seen that evapotranspiration may be evaluated from the water vapor gradient if simultaneous measurements of the gradients of the temperature or wind movement and of the flux of sensible heat or momentum are made at the same site. However, independent measurements of sensible heat or momentum flux are difficult to achieve and have thus been used only rarely.

The assumption of similarity in eddy transfer coefficients for momentum, water vapor, and heat holds reasonably well only during near neutral or non-buoyant conditions of stability. These conditions do not commonly hold all the time. Evidence has been presented in the literature which both supports and condemns the assumption of equality of the transfer coefficients under various conditions of atmosphere stability.

To achieve more accurate estimates of evapotranspiration, it has become necessary to adjust aerodynamic calculations for their dependency on

stability. There are several forms of stability correction forms, such as the Richardson number or the Monin-Obukhov (1945) mixing length.

The aerodynamic method will be combined with other methods such as energy-balance or empirical methods to produce a method for use at information levels two and three in our proposed remote-sensing-aided evapotranspiration system.

The aerodynamic equation, discussed in Appendix I, can be used for the direct estimation of evapotranspiration. It required wind and vapor concentration measurements at two heights above the surface and temperature measurements for the stability correction. The measurement accuracies required are high, since the differences are small.

II 5.0 Combination Methods

Perhaps the most widely used method for computing lake evaporation from meteorological factors is based on a combination of aerodynamic and energy-balance equations such as those as Penman, Ferguson, and Slatyer and McIlroy.

Combination methods are the only methods that are based on physical processes and yet do not require highly specialized measurements.

Several of these methods will be appropriate at information resolution levels two and three in our proposed remote sensing-aided evapotranspiration estimation system.

Penman's original equation has been applied fairly successfully in a range of climates, but it is only applicable to free water surface evaporation. The lake evaporation computed for short periods by this method would be appropriate only for very shallow lakes with little or no advection of energy to the lake.

According to Penman (1956) the potential transpiration rate is determined by the prevailing weather conditions and, for a crop completely covering the surface, the rate is about the same irrespective of plant or soil type. A corollary of his equation is that transpiration (from a short green cover) cannot exceed the evaporation from an open water surface exposed to the same weather. More recent research into aerodynamic roughness factors suggests some significant variations between crop types, while Tanner and Pelton (1960) indicate that crop transpiration can exceed free water loss particularly when there is appreciable advective transfer of heat. However, natural vegetations are taller and aerodynamically rougher than turf and the Penman equation estimates are usually too low under these conditions. On the other hand, estimates may be too high in windy regions.

Slatyer and McIlroy (1961), developed a formula which in form closely resembles Penman's original equation. Apart from using wet-bulb depression instead of saturation deficit, the essential difference is that several factors neglected by Penman are taken into account.

The McIlroy et al. equation represents a more realistic model of transpiring vegetation than the Penman type, but the introduction of crop surface and soil water parameters serves to complicate the model. Unless these parameters are evaluated for conditions at the site for which evaporation estimates are required, then the estimation is essentially empirical.

The major difficulty preventing this method's wide application is the difficulty in evaluating the wind function $h = a (b + u)$, as the empirical constants (a and b) depend on the nature of the surface. This requires some years of comparison with some standard method of evaluating evaporation

such as lysimetry or energy balance.

The McIlroy et al. formula contains two quantities, h and D_o , which must be solved before it can be applied.

A commonly used method of estimating evapotranspiration is to determine potential evapotranspiration and then to use an empirical relationship of $ET_{actual}/ET_{potential}$. Micrometeorological studies of forests have already led to analysis of differences in evapotranspiration from different cover types. All the relevant surface variables - albedo, surface temperature, roughness, stomatal resistance, root and soil water properties - as well as necessary meteorological variables - cannot be considered altogether in any current model at the present time.

11 5.1 McNaughton and Black's Model

McNaughton and Black used Monteith's Canopy transpiration model (Monteith, 1955) for part of their model. Monteith (1965) determined the effect of diffusive resistance to water vapor from vegetation canopy by considering the canopy as a single extensive isothermal leaf. The McNaughton and Black's model considers only one-layer of the canopy and has attracted several criticisms (Philip, 1963, 1966 and Tanner, 1968). These criticisms arise from the observation that the simple one-layer model ignores leaf boundary layer diffusion resistances and aerodynamic diffusion resistances between different levels of the canopy. In general, the surface resistance cannot be vigorously identified with the stomatal resistance of all of the leaf surfaces acting in parallel and such interpretation must be justified by examination of the assumptions for each canopy studied.

Good wind profile data for calculation of r_a in the McNaughton and Black model is frequently unavailable.

In this method γ_s is computed from Monteith's canopy transpiration equation,

$$E = \frac{E_o}{1 + \frac{(\gamma)}{\gamma+s} \frac{r_s}{r_a}}$$

Therefore, the effect of an error in r_a term on the value of " r_s " calculated from the above equation can result in errors in the value of " r_s " as well.

Cowan (1968) and Thom (1972) have examined the assumption of similarity of the aerodynamic diffusion resistance for momentum and those for heat and water vapor. Both investigators consider that the assumption of similarity may not be appropriate for exchange within the canopies. However, in calculating r_s for forests from the above-mentioned equation, the major uncertainty will usually be caused by errors in the measured values of transpiration.

11 5.2 Priestly and Taylor Model

A more practical form of combination method is presented by Priestly and Taylor (1972), which gave reasonably good results when applied to a forest watershed. The value of the coefficient α in their model represents the only empirical coefficient and they found its best value to be 1.26; this is its mean value over terrestrial and water surfaces. The primary variable in their model is net radiation.

The apportionment of net radiation between heat flux and evaporation requires a knowledge of the distribution of net radiation itself. The problem

of mapping net radiation is not different in kind from those of temperature, wind, rainfall, etc. However, the mapping of net radiation will be highly sensitive to the knowledge and predictability of cloud amount and type. In this case remote sensing seems to be an especially good and appropriate information gathering tool to use.

Given net radiation, potential evapotranspiration can be estimated from the Priestly and Taylor model.

II 5.3 Modified Linacre Method

Stephan and Stewart (1963) appear to be the first specifically to associate the ratio LE/Q_s with the mean ambient temperature, T , where LE is evapotranspiration and Q_s is the total incoming solar radiation (Linacre, 1967). Their observations were quickly followed by the results of several other investigators. Linacre (1967) deduced the ratio LE/Q_s by means of four basic equations. The first is analogous to Penman's formula for lake evaporation, the second concerns the net-radiation flux, Q_n , expressed in terms of its components; the third is an equation for the net upward flux of longwave radiation, Q_{nL} ; and the fourth is an approximation for the solar radiation flux, Q_s . The final formula for estimating ET/Q_s in this method employs temperature, ambient saturation vapor deficit, a cloudiness term, and the type of surface cover in terms of aerodynamic and vegetation resistances as well as albedo.

II 6.0 Empirical Formulas

A large number of empirical methods have been developed for the estimation of evaporation from open water surfaces or from vegetation. With most of these procedures the objective has been to use commonly measured meteorological elements, and the equations range from those using simple mean dry-bulb temperature to sophisticated physical relationships which attempt to use all the parameters controlling evaporation.

Qualified technicians have little justification in using empirical methods when the basic meteorological parameters such as net radiation, vapor pressure and temperature gradients, wind speed at a prescribed elevation above the vegetative canopy or over a standard surface, and soil heat flux are available.

Empirical methods have been used to estimate evapotranspiration from measured evaporation loss of a pan or from standard surfaces such as short, smooth, and water saturated crops, or from one or a few meteorological parameters such as air temperature, saturation deficit, or solar radiation. But the applicability of these or any other such methods to the forest should be tested cautiously.

Several of these methods will find application in information level 1 of our proposed remote-sensing-aided evapotranspiration systems. That is, these models may be driven efficiently by information obtainable at the LANDSAT level of resolution.

11 6.1 Thornthwaite Method

Certain shortcomings are inherent in this method. For example, evapotranspiration lags the annual maximum heating during the late spring and is consequently out of phase in the fall as well. (Rosenberg, et al., 1968). Furthermore, application of the Thornthwaite concept to short time periods leads to significant errors as a result of the often excessive variation in mean air temperature during these periods.

Leeper (1950) obtained anomalous results with the Thornthwaite method applied to various Australian locations where mean temperatures were similar but where the actual climate differed greatly (two climates may have the same average temperature with different temperature variations, maximums and minimums) with consequent differences in known evapotranspiration as well.

Marlatt et al., (1961) found that the Thornthwaite method, applied to snap beans on sandy loam, gave good estimates of evapotranspiration until 25mm of water was removed. After 25mm of water loss, evapotranspiration proceeded asymptotically to a linear decrease in water loss.

11 6.2 The Blaney-Criddle Method

This method is based primarily on temperature and humidity data. It is easy to use. Necessary data are readily available from climatological

stations, and results have been sufficiently accurate for many practical applications.

This method has been used by several researchers, and scientists around the world. It has been found to be satisfactory for computing water use where measured water consumption data are not available.

11 6.3 Hargreaves' Formula

Hargreaves' formula uses the same climatic factors as the Blaney-Criddle formula, but makes the evaporation proportional to the centigrade temperature. Hargreaves substituted a constant, (0.38), for the monthly coefficient, k , and thus does not leave this to the judgment of the user. According to Christiansen (1966), comparisons of Hargreaves formula by Patel and Christiansen (1963), Al-Barrak (1964), and Chindasnguan (1966) indicate that the Hargreaves formula gives fairly good results for normal wind values (average wind movement of 60 miles per day) when applied to a wide range of climatic conditions.

Hargreaves estimated evapotranspiration by multiplying the computed or measured pan evaporation by a monthly coefficient, k , which he determined for a wide variety of crops. Since pan evaporation integrates many of the effects of the different climatic factors, it provides a good base for the estimation of monthly evapotranspiration values.

The Hargreaves method is applicable to both arid and humid climates and to locations where data are quite complete as well as to those locations or projects for which only temperature and rainfall data are available.

11 6.4 Christiansen's Formula

Christiansen's formula produces good results when data are available for temperature, wind, humidity, percent of possible sunshine, and elevation. There seems, however, to be a real possibility that engineers and agriculturalists will at first glance assume that complete data are required in order to use this formula. This is not necessarily the case. By making use of the equation derived by Mathison (1963)

$$H = 113 - 2.5 \Delta T$$

in which H is relative humidity at noon in percent and ΔT is maximum temperature minus minimum temperature, in $^{\circ}\text{F}$, (average for the period considered), the Christiansen's formula can be used with only data for temperature and approximate elevation. Wind and percentage of possible sunshine can be estimated based upon their probable departures from normal or average conditions. Average conditions are represented in the tables by a coefficient of 1.00.

These average (normal) conditions are 60 miles of wind movement per day and approximately 90 percent sunshine.

11 6.5 Jensen and Haise Method

Jensen and Haise (1963) developed a rational empirical (semiempirical) method for estimating or predicting evapotranspiration, using solar radiation as the primary variable. Empirical methods using radiation are more reliable for both short and long-time periods than those using meteorological parameters that are not a measure of available energy or basic components of

energy balance equations.

In this method heat flux to the vegetation and energy used for photosynthesis have not been included since they are a normally negligible part of the total energy required for evapotranspiration. Over time periods of a week or more the heat flux to the soil is also negligible. Heat flux to the air (the advective term) may be important, especially in areas with significant wind movement.

Improvements in the Jensen and Haise model could be gained by consideration of several meteorological parameter effects currently not incorporated in the method. For instance, improvements in estimated values of solar radiation by use of a temperature correction factor are not considered. For a given solar radiation value, temperature will normally show some correlations with latitude (effect on reflectance) and relative humidity (David and Robb, 1966). Temperature would be expected to vary directly with the amount of advected energy (-A) available also. Since transpiration is the major mechanism for plant cooling, the temperature of surrounding air has an important direct effect on the plant. This may be considered a shortcoming for this model. Relative humidity has a direct effect on the vapor pressure gradient and may also affect the amounts of short-wave solar radiation and thermal radiation reaching the plants. Wind has an important effect on the advective energy term because of its effect on the rate of convective cooling. The relative importance of these terms is greatly affected by plant canopy characteristics, so the ideal of defining a climatic factor which accounts for "all climatic effects" probably can never be achieved. The effect of soil moisture in this model has been considered

negligible, but the effect of moisture stress on evapotranspiration could be evaluated.

II 6.6 Turc's Model

Turc (1954) suggests the equation for estimating annual evapotranspiration based on annual precipitation and L, a function of mean annual temperature, Pike (1964) tested Turc's method in forested watersheds in Malawi, and found that it underestimated actual ET by amounts ranging from 6 to 17 percent. He modified Turc's formula by introducing Penman's E. Instead of L, or utilized data from adjusted evaporation pans. Lewis (1968) used Pike's equation to evaluate consumptive use in the Placer County, California watershed. He used Penman's E. values for 10 months (October-July) for ET estimation on oak woodlands. Estimates of ET by Lewis departed from actual values by 3 to 34 percent (Burgy and Papzafirion, 1971).

References

For references, see section 2.500b.

APPENDIX III

PROCEDURE FOR MEASURING SECONDARY SAMPLING

UNIT GROUND PLOTS FOR WATER

LOSS ESTIMATION

Randall W. Thomas

APPENDIX III PROCEDURE FOR MEASURING SECONDARY SAMPLING UNIT GROUND
PLOTS FOR WATER LOSS ESTIMATION

Field Instructions for Water Related Variables

I. Non-Living Component

A. Fill in date, crew code, photo plot number, and note starting time on Sheet NL1.

B. Line Data for Sheet NL1.

1. Locate photo plot center; this will be point number 6 in a 100 foot line sectioned into 10 foot intervals and oriented along the topographic contour running through the photo plot center. Point number 1 will be located at the end of the line in the western hemisphere.
2. Record Azimuth of the line to the nearest degree.
3. Locate the exact photo center point, i.e. line point number 6. Record the surface for line point number 6 according to instructions contained in the recording form key.
4. At line point 6 determine and record the Munsell Color Code (hue, value, chroma from the soil booklet) for the surface litter, if any. This determination should be made with direct sunlight on both the organic material and color charts if possible. Use organic material lying directly on the surface.
5. Then at line point number 6 use the garden trowel to dig through the organic (or duff layer) just to the top of the mineral soil. Measure and record the depth of the organic layer to the nearest 1/16 inch.
6. Starting at line point number 6 (photo center) pace along the line in one direction, say towards line point number 7. Be sure to accurately calibrate your pace to 10 feet.
7. At the tip of the boot just touching the next 10 foot line point, in this case line point number 7, record the surface at that point according to instructions on the recording form key.
8. Repeat steps I.B. 4 and 5 at the position where the surface is described at line point number 7.
9. Mark the exact location of line point number 7 with a marker placed into the ground.
10. Standing at line point number 7, turn and face line point number 6. Proceed to make ocular estimates of the percent of bare mineral soil, rock, and dead organic matter greater than 1/4" along the line from line point number 6 to line point number 7 and record these values to the nearest 10%

in the appropriate columns of the data form for the row labeled 6-7. Where brush or other obstructions obscure the line between the two line points, then make ocular estimates from both points to obtain an average percent of line figure.

11. Turn again to face line point number 8 and pace 10' to line point number 8. Again record the surface at the tip of the boot touching line point number 8 and repeat steps I.B.4 and 5. Make ocular estimates as in step I.B.6 for the interval 7-8.
12. Proceed similarly for line points numbers 9, 10, and 11.
13. Locate line point number 11 exactly with a marker placed into the ground.
14. At line point number 11 turn and face line point number 6. Take a 35 mm photograph back along the line to illustrate the general vegetative and surface condition. Record roll and frame no.
15. Return to line point number 6 (the photo center).
16. Pace 10 feet to line point number 5. Proceed to record surface conditions, the surface Munsell Color Code, the organic matter layer thickness, and make ocular line estimates as in steps I.B.3, 4, 5, and 10 respectively.
17. Mark the exact location of line point number 5 with a marker placed in the ground.
18. Proceed as in step I.B.16. for line point numbers 4, 3, 2, 1.
19. Locate with a marker the exact location of line point number 1.
20. At line point number 1 turn and face line point number 6. Take a 35 mm photograph back along the line to illustrate the general vegetative and surface condition. Record roll/frame no.
21. At line point number 1 dig into the mineral horizon. Remove soil material from the depth of 1 1/2 to 2 inches (where 0" would be at the top of the mineral soil) and determine and record its Munsell color code. Please make the determination with direct sunlight on the soil and the color charts if possible.
22. Dig further to 3" depth within the mineral soil horizon at line point number 1. Place material from within the 0-3 inch mineral soil horizon zone in the soil sieve. Fill the sieve to the top and place the lid on it. Shake until no further significant soil (<2mm fraction) falls out the bottom. Remove the lid and check to see if the sieve is clogged by moist soil. If it is, please unclog the sieve, replace the lid and shake again. When no further soil can be removed by sieving, make an estimate of the volume of material remaining

in the sieve can to the nearest 10%. Then by moistening the "clumps" remaining in the sieve determine the percent volume (expressed as a fraction from 0 to 1.0) of the remaining material which is indeed rock. Then a calculation of the percent of 0"-3" mineral material volume greater than 2 mm will be formulated as

$$\% \text{ vol. } > 2 \text{ mm} = \left(\text{est. of } \% \text{ vol. remaining} \right) \left(\text{Fraction (0-1.0) of vol. remaining which is rock} \right)$$

Record the final result as the percent of 0"-3" mineral material volume >2 mm.

23. Return to line point numbers 5, 6, 7, 11 (in that order) and repeat steps I.B.21 and 22.
24. Determine soil texture from line pt. no. 11 by utilizing material from the 1 1/2" to 2" depth in the mineral horizon. Place this material in the palm of the left hand and wet it until the mass behaves plastically. Check for small grittiness (by feel and by grinding sound when thumb and index finger are rubbed close to ear) indicating sand, or large grittiness indicating gravel (>2 mm - 3"). Slight sponginess yet failure to form significant cohesive ribbons will indicate loams (generally equal parts sand, silt, and clay), a slick feel without ribbons will indicate silts, and significant ribboning will indicate clay. See the recording form key for notation.
25. Repeat step I.B.24 at line points no. 7, 6, 5, and 1 (in that order).
26. When surface material prevents top soil horizon color, texture, and percent mineral material volume greater than 2 mm from being determined at the specified line point number, then proceed to the nearest line point number and make these determinations.

C. Additional Information for Sheet NL1.

1. From line pt. no. 6 determine the slope and aspect for the plot.
2. Characterize the general microrelief over the line.
3. Where a soil profile is exposed please obtain the information requested. All depths should be measured from the top of the mineral soil.
4. General comments: e.g. characterize the frequency (spacing), width, and depth of surface erosion features. Note whether gully or sheet (uniform surface) erosion, presence of pedestaled plants or rocks, presence of mini-alluvial fans, etc.
5. Locate a down log or large sharp angular rock near the center of the plot or preferably crossing the center of the plot which which lies in a significant forest canopy opening large enough

to allow the object to be imaged in sunlight from the air. Measure accurately the length of the log or an airphoto distinguishable section of it. In the case of a rock, measure its largest diameter. Measure also the slope along which the log long dimension or the rock largest diameter lies. Record this information (to be used to calculate photo scale) on the back of Sheet NL1.

6. Note time at which Non-living Component information recording for parts I.A,B,C is finished and record the total time taken to perform measurements on the Non-living Component for these parts.
7. Please remember to collect and check all equipment including line point markers before leaving the plot.

D. Soil Profile Information

1. Note and record the time on the back of Sheet NL1 at which soil profile information gathering was started.
2. If possible shelf with a shovel a soil profile four inches downslope from line point number 6. When shelving becomes unfeasible then continue vertically into the soil profile with an auger. If a surface rock or root prevents shelving or auguring then locate the soil pit at the point nearest the plot center which will allow the soil profile to be examined. Record the azimuth and distance to the center of the pit with respect to the plot center.
3. Be careful to evenly lay out each auger headful from top to bottom, connecting the top of successive auger headfuls to the bottom of the previous one. The length of the excavated soil material pile for each auger headful should be equal to the length of the auger head containing soil for that headful. Please note when done the top and bottom ends of the profile.
4. Label the "Field Sheet for Recording Soil Characteristics" with the appropriate photo plot number and line point number.
5. Locate and mark the soil profile horizons along the excavated soil material profile.
6. Measure the length (depth) of the soil horizons and sketch the profile on the recording form.
7. Determine and record for each soil horizon the Munsell soil color code, the texture (code according to instructions in the key on front of sheet NL1), structure, consistence, reaction, and miscellaneous characteristics. Each information type requested should be determined according to the "Definitions and Abbreviations for Soil Descriptions" USDA-SCS publication dated Oct. 1966 in your possession. Notation should also be as given in this publication except for texture as noted above. If a more refined determination of texture is possible, then also record this more precise determination according to the notation given in the USDA-SCS publication.

8. Determine and code Drainage and Erosion according to the USDA - SCS publication. Enter the codes on the appropriate lines of the recording form (Field Sheet for Recording Soil Characteristics).
9. Measure and record the depth to water table (groundwater) if it is present in the profile.
10. Repeat all steps above at either line point numbers 5 or 7 if the soil type appears to be different at these locations from that examined at line point number 6. The decision as to whether the soil type is in fact different will depend on examination requested for Sheet NL of top soil texture, color, percent greater than 2 mm volume. Remember to offset the soil pit 4 inches downslope from these line points and also please remember to label each "Field Sheet for Recording Soil Characteristics" with the appropriate photo plot and line point number.
11. When finished with the three soil profiles please note and record the time on the back of Sheet NL1 and by subtraction determine and record the total time spent on the soil profiles.

Field Instructions for Water Related Variables

II. Living Component

- A. Fill in date, crew code, photo plot number, and record the starting time (remember to record finishing time at the end and then determine total time at plot for Living Component).
- B. Locate a 0.01 acre circular plot centered at the selected photo plot center. Utilize the 0.01 acre plot rope with a radius length of 11.78 feet to accurately locate the plot boundary.
- C. Please read the recording form definitions in Table I.
- D. Sheet No. L1

1. Record on the azimuth marked circle diagram at the right of Sheet No. L1 (representing the 0.01 acre plot with a 11.78 foot radius) the crown outline at maximum crown perimeter for all trees (conifer and broadleaf) having main stem dbh \geq 5.5 inches and which have part of their crown over the 0.01 acre plot. Be sure to locate trees according to their proper azimuth. Indicate by dotted lines boundaries for trees whose crowns are overtopped by others. Please extend the crown boundaries for trees satisfying the above criteria beyond the circle on the recording form to the extent that it is practical from ground observation and according to recording form space.

Give each tree dealt with above an index number starting at one and continuing as 1, 2, 3, Indexing should start with the tree whose stem is closest to zero azimuth and then proceed clockwise. Draw an arrow from the index number to the crown boundary to which it belongs.

2. Enter in the left-most information column of Sheet No. L1 the index number used for each tree in the diagram at the right. Then place a "slash" mark and give the species code given in Table II. If the identity of a plant can not be determined, then use the code "UK" followed by a "/" and then the code for the plant taxon most closely resembling the unknown plant. Please record a zero in the left-hand index code columns (columns are indicated by "X's") that are not used.
3. Proceed through the remaining information columns from left to right.

- a. dbh should be measured on the largest main stem of a tree with a D-tape. Observations should be recorded to the nearest 0.1 inch.
- b. The heights requested should be estimated to the nearest 2 feet for conifers and the nearest 2 feet for broad-leaved trees.
- c. Distances requested should be determined by pacing from the plot center. Values should be recorded to the nearest 0.1 foot.
- d. When recording values for D_1 the approximate location of the main stem for the given tree should be located and annotated on the crown area diagram at the right.
- e. Record vertical foliar density (viewed looking upwards) for broad-leaved trees to the nearest 10%.

For all information types above, please record a zero in left-hand data columns (columns are indicated by "X's") that are not used.

4. If two copies of Sheet No. L1 are needed, then record a "2" in the underlined portion of the "Page 1/ " data item located in the upper right-hand corner. Otherwise, record a "1". On the second page record "Page II/2".

E. Sheet No. L2

1. Complete the diagram for crown area at maximum perimeter for trees (conifer and broad-leaved) having largest main stem dbh < 5.5 inches and total height > 6 feet. Please follow instructions as outlined in II.D.1.
2. Proceed through information columns from left to right.
 - a. dbh should be measured to the nearest 0.1 inch.
 - b. All height information should be estimated to the nearest 1 foot. Record height information for the bulge point only if a definable bulge point exists.
 - c. All distance information should be determined by pacing to the nearest 0.1 foot. Please locate and annotate main stems on the crown area diagram as described in II.D.3.d. Distance to bulge point should be determined only if a definable bulge point exists.
 - d. Vertical foliar density (viewed looking upwards) should be estimated to the nearest 10%.

e. Leaf data should be recorded as indicated in Table I.

F. Sheet No. L3

1. Trees (conifer and broad-leaved) having largest main stem dbh < 5.5 inches and height 6 to 2 feet inclusive: Proceed as in the applicable steps from II.D. except that height information should be determined to the nearest half-foot and vertical foliar density may be determined by either viewing upwards or downwards through the crown. Please remember to locate and annotate main stems on the diagram.
2. Age for conifers (nearest year) should be determined by counting the number of major branch whorls starting from the main stem base and proceeding to the stem top.
3. Both horizontal and vertical foliar density should be estimated to the nearest 10 percent.

G. Sheet No. L4

1. Please do part E on Sheet L4 for shrubs whose vertical projection of continuous canopy exceeds 1 foot diameter at the widest point (project onto a level plane). A continuous canopy is defined as a leaf matrix with overlapping leaves when viewed vertically. Its vertical foliar density can be less than 100%. If the shrub's continuous canopy density is less than one foot at its widest point then the information for that shrub plant should be recorded under part D. on Sheet L4. Don't count shrub individuals or their crown area in part D. that were included under part E. For shrubs included in part E, proceed as in the applicable steps from II.D. Note that maximum brush height (nearest 1/2 foot) should be estimated for that part of the brush plant falling within the 0.01 acre plot.
 2. For trees (conifer and broad-leaved) with largest main stem dbh < 5.5 inches and with height < 2 feet, the total number of individual plants by species should be recorded (use tally meter if necessary). Also include shrubs in this table whose vertical projection of continuous crown canopy is less than one foot diameter at the widest point (project onto a level plane) as described in II.G.1. above. The estimated crown area at maximum perimeter expressed as a percent of the 0.01 acre plot area for each plant of a given species should be added together to give the total cumulative crown area for that species. The data value should be expressed as a percent of the 0.01 acre plot area to the nearest 5 percent.
 3. A total cumulative crown area estimate should be made according to the method of II.G.2. for each component of herbaceous vegetation. Note that a forb is defined to include broad-leaved non-woody vegetation commonly referred to as "weeds" and "wildflowers."
- H. When finished with Sheet No. L4 note the time and return to Sheet No. L1 and record the total time taken to perform measurements on the Living Component. Also check to see that each Sheet has the correct photo plot number recorded.

Table I Definitions for Recording Form Sheet No.'s L1, L2, L3, and L4

Vegetation to be analyzed: Includes all plants whose vertical projection of crown area covers some portion of the 0.01 acre plot.

dbh: diameter at breast height (approximately 4.5 feet)

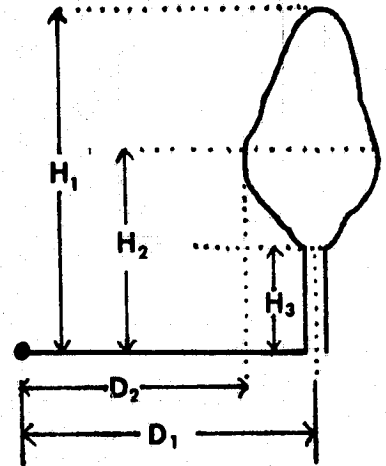
H_1 = estimate of height (vertical distance) from ground to plant top (see illustration)

H_2 = estimate of height (vertical distance) from ground to point of maximum canopy radius. The point of maximum canopy radius is defined as the bulge point.

H_3 = estimate of height (vertical distance) from ground to bottom of live crown defined by lowest location for a significant leaf mass.

D_1 = paced distance from 0.01 acre plot center to midpoint of largest main stem axis.

D_2 = paced distance from 0.01 acre plot center to a point on the ground defined by the vertical projection of maximum crown perimeter (bulge point) closest to the plot center, i.e. along the plot ray originating at the origin and passing through the main stem axis.



vertical foliar density: ocular estimate of percent background obscured by foliage when viewing vertically through the crown at an average crown thickness. The estimate must be made viewing upwards for large trees and may be made looking downwards for very small trees.

horizontal foliar density: ocular estimate of percent background obscured by foliage when viewing through the crown at average crown depth (direction parallel to slope).

vertical foliar and woody density:

ocular estimate of percent of background obscured by foliage and woody plant parts when viewing vertically through the crown at average crown thickness.

horizontal foliar and woody density:

ocular estimate of the percent background obscured by foliage and woody plant parts when viewing through the crown at average crown depth (direction parallel to slope).

herbaceous vegetation: living non-woody plants

- grass-like: includes grasses and sedges
- forbs: includes broad-leaved non-woody plants commonly referred to as "weeds" and "wildflowers"
- fern: a rhizomatous non-woody plant

Leaf Data

For firs, Douglas-fir, pines, yew, nutmeg and hemlock: Data for a single tree should be coded as:

- I $[(u_1, \bar{u}_1, v_1, x_1, y_1, z_1)/(u_2, \bar{u}_2, v_2, x_2, y_2, z_2)/(u_3, \bar{u}_3, v_3, x_3, y_3, z_3)/\dots]$ OB,OL,n,a,b,c
- II $[(u_2, \bar{u}_2, v_2, x_2, y_2, z_2)/(u_3, \bar{u}_3, v_3, x_3, y_3, z_3)/\text{maximum } t]$ OB,OL,n,a,b,c
- III $[(u_2, \bar{u}_2, v_2, x_2, y_2, z_2)/(u_3, \bar{u}_3, v_3, x_3, y_3, z_3)/\text{maximum } t]$ OB,OL,n,a,b,c

where

I, II, III: represent branch sample number. Branch I is branch closest to the plot center at breast height. Branches II and III are located respectively clockwise 1/3 and 2/3 around the tree from Branch I. They are the branches closest to breast height at these locations.

a = azimuth of branch (nearest 5°) measured relative to the tree main stem (origin).

b = average tilt (nearest 5°) of overall branch leaf mass to right (positive) or to left (negative). Use "NA" if not applicable.

c = overall leaf covered branch slope (nearest 5°), with up positive, down negative. If more than one distinct slope, record each separately followed in parentheses by the t values corresponding to each segment.

n = width (nearest 1/2") of branch segment supporting emerging foliage.

u_t = average Munsell plant tissue color code for year t for upper leaf surface (make 4 to 5 estimates randomly located).

\bar{u}_t = average Munsell plant tissue color code for year t for lower leaf surface (make 4-5 randomly located estimates).

v_t = average needle width (nearest 1/32") for year t (take 4-5 random measurements).

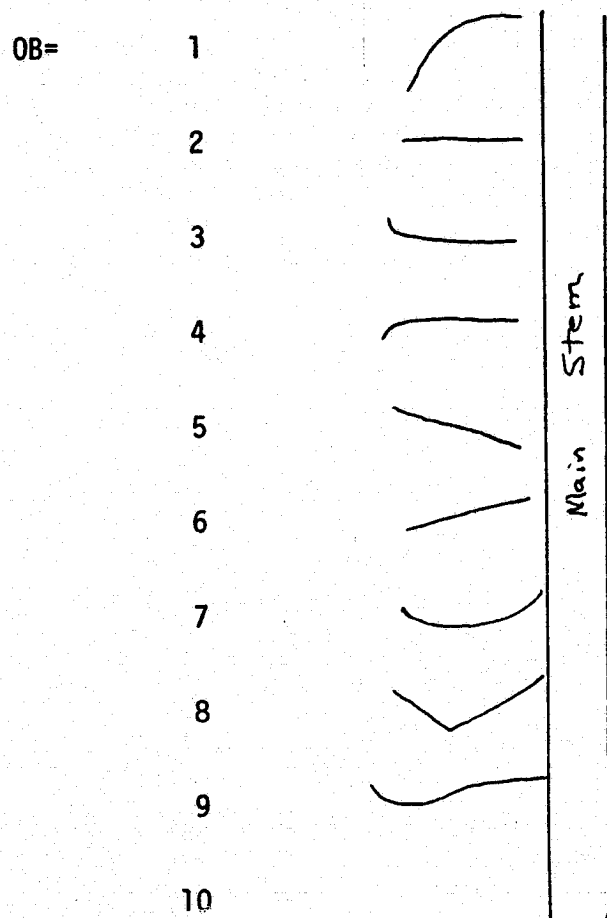
x_t = yearly branch length (nearest 1/8") for year t; measured from end of previous year's needles to end of year t's needles.

y_t = average needle length (nearest 1/8") for year t (take 4-5 random measurements)

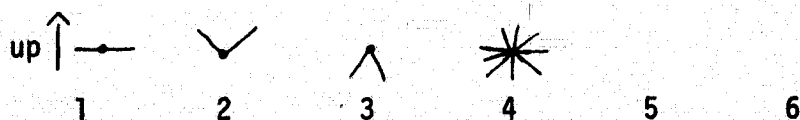
z_t = average number of needles per inch along one side of branch for year t

t = 1 (this year), 2 (last year), 3 (year before last), ... until point at which no significant amount of needles remain.

OB = average leaf covered main branch axis shape when viewed from the side.



OL = average needle spray geometry when viewed in cross section.



Two trees for a given species should be selected for the above measurements. These two trees will be the ones with reachable needles located closest to the 0° and 180° azimuth and also with main stems closest to the plot perimeter.

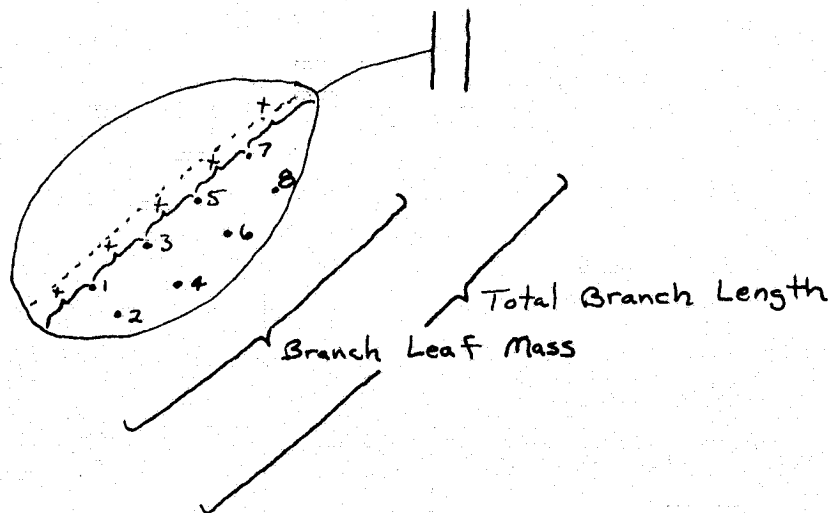
For cedar and juniper: Data for a single tree should be coded as:

- I [OB,OL,a,b,c,m,n,(k₁,k₁),(k₂,k₂),...,(k₈,k₈)]
 II [OB,OL,a,b,c,m,n,(k₃,k₃),(k₄,k₄)]
 III [OB,OL,a,b,c,m,n,(k₃,k₃),(k₄,k₄)]

where

I, II, III: defined and located as in the case of fir

k₁,k₂,...k₈=Munsell plant tissue color code for the upper leaf surface measured at eight similarly located points shown below. The distance X should be constant. Each pair (e.g.1 and 2) should be located on a line perpendicular to the branch axis. The inner point should be 1/4 way to the branch leaf mass edge and the second point 3/4 way to the branch leaf mass edge.



k₁,k₂,...k₈=Munsell plant tissue color code for the lower leaf surface measured at the same eight points as above.

m =length (nearest 1/2") of branch segment supporting emerging foliage.

Two trees should be selected for these measurements according to the criteria for fir.

For broad leaved trees: Data for a single tree should be coded as:

I [OB,OL,a,b,c,m,n,(r₁,s₁,p₁,d₁,l₁, $\bar{l}_1),(r₆,s₆,p₆,d₆,l₆, $\bar{l}_6),
(r₁₁,s₁₁,p₁₁,d₁₁,l₁₁, \bar{l}_{11}),(r₁₆,s₁₆,p₁₆,d₁₆,l₁₆, \bar{l}_{16})]$$

II ["]

III ["]

where

I, II, III : defined and located as in the case of fir

g = leaf index number; "1" represents the leaf with petiole closest to the main branch tip, "6" represents the leaf with petiole 6th closest to the main branch tip, etc. Where leaves are simple opposite, count each pair as one leaf and flip a coin to determine which leaf of the 6th pair will be measured. If several side branches are attached to the main branch then proceed as before on the main branch, except that when a side branch is encountered go to the tip of that side branch and continue to count leaves down its length.

r_g = length (nearest 1/8") of selected leaf from leaf base to tip.

s_g = width (nearest 1/8") at maximum width of the leaf whose length (r_g) was measured.

p_g = percent (nearest 10%) of hypothetical maximum leaf area (no sinuses or indentations) actually taken up by leaf surface.

d_g = depth (nearest 1/32") of sinus or indentation nearest the maximum leaf width position.

l_g = Munsell plant tissue color code for the upper leaf surface.

\bar{l}_g = Munsell plant tissue color code for the lower leaf surface.

Two trees for a given species should be selected for these measurements according to the criteria outlined for fir.

TABLE II

I. Tree Codes

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
ABCO	<i>Abies concolor</i>	White Fir
ABMA-2	<i>Abies magnifica</i>	Red Fir
ACMA	<i>Acer macrophyllum</i>	Broadleaf Maple
ALN-2	<i>Alnus species</i>	Alder
ALRH	<i>Alnus rhombifolia</i>	White Alder
ARME-3	<i>Arbutus menziesii</i>	Madrone
BEOC-2	<i>Betula occidentalis</i>	Water Birch
CADE	<i>Calocedrus decurrens</i>	Incense Cedar
FRA10	<i>Fraxinus species</i>	Ash
JUN-5	<i>Juniperus species</i>	Juniper
JUOC	<i>Juniperus occidentalis</i>	Sierra Juniper
LIDE-2	<i>Lithocarpus densiflora</i>	Tan-bark Oak
PIAL	<i>Pinus albicaulis</i>	Whitebark Pine
PIAT-1	<i>Pinus attenuata</i>	Knobcone Pine
PICOM	<i>Pinus contorta</i> var. <i>murrayana</i>	Lodgepole Pine
PIJE	<i>Pinus jeffreyi</i>	Jeffrey Pine
PILA	<i>Pinus lambertiana</i>	Sugar Pine
PIMO-2	<i>Pinus monophylla</i>	Pinon Pine
PIMO-3	<i>Pinus monticola</i>	Silver Pine (also Western White Pine)
PIPO	<i>Pinus ponderosa</i>	Ponderosa Pine (also Yellow Pine)
PISA-2	<i>Pinus sabiniana</i>	Digger Pine

TABLE II (cont.)

Tree Codes Continued

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
PLRA	Platanus racemosa	California Sycamore
PSME	Pseudotsuga menziesii	Douglas-fir
POFR-3	Populus fremontii	Fremont Cottonwood
POTR-3	Populus tremuloides	Quaking Aspen
POTR-4	Populus trichocarpa	Black Cottonwood
QUCH-2	Quercus chrysolepis	Canyon Oak (also Golden Oak)
QUKE	Quercus kelloggii	California Black Oak
QUWI	Quercus wislizenii	Interior Live Oak
TABR	Taxus brevifolia	California Yew
TOCA	Torreya californica	California Nutmeg
TSME	Tsuga mertensiana	Mountain Hemlock
UMCA	Umbellularia californica	California Laurel (also California Bay)

II. Shrub Codes

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
ACE-1	Acer species	Maple
ADFA	Adenostoma fasciculatum	Chamise
ALN-1	Alnus species	Alder
ALTE	Alnus tenuifolia	Mountain Alder
AMPA-2	Amelanchier pallida	Service Berry
ARC-5	Arctostaphylos species	Manzanita
ARMA-3	Arctostaphylos manzanita	Common Manzanita

TABLE II (cont.)

Shrub Codes Continued

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
ARME-2	Arctostaphylus Mewukka	Indian Manzanita
ARNE-2	Arctostaphylos nevadensis	Pinemat Manzanita
ARVI-3	Arctostaphylos viscida	Whiteleaf Manzanita
ART-5	Artemesia species	Sagebrush
ATR-3	Atriplex species	Saltbush
CAOC-2	Calycanthus occidentalis	Spice-Bush
CEA	Ceanothus species	California Lilac
CECO-2	Ceanothus cordulatus	Mountain Whitehorn
CECU-2	Ceanothus cuneatus	Buck Brush
CEIN-3	Ceanothus integerrimus	Deer Brush
CEJE	Ceanothus jepsonii	
CEPR	Ceanothus prostratus	Squaw Carpet
CEVE-3	Ceanothus velutinus	Tobacco Brush
CEOC	Cercis occidentalis	Redbud
CER-8	Cercocarpus species	Mountain-Mahogany
CHFO-2	Chamaebatia foliolosa	Kit-kit-dizze (also Mountain Misery or Bear Clover)
CHSE	Chrysolepsis sempervirens	Bush Chinquapin
CHR-9	Chrysothamnus species	Rabbit Brush
CLLI-2	Clematis ligusticifolia	Western Clematis
COR16	Cornus species	Dogwood
CONU-2	Cornus Nuttallii	Mountain Dogwood

TABLE II (cont.)

Shrub Codes Continued

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
COST-3	<i>Cornus stolonifera</i>	American Dogwood (also Creek Dogwood)
COCOC	<i>Corylus cornuta</i> var. <i>californica</i>	Hazelnut
CYSC-2	<i>Cytisus scoparius</i>	Scotch Broom
DERI	<i>Dendromecon rigida</i>	Bush Poppy
DIP	<i>Diplacus species</i>	Bush Monkey-Flower
ERCA-6	<i>Eriodictyon californicum</i>	Yerba Santa
ERI21	<i>Eriophyllum species</i>	Yarrow
GAFR	<i>Garrya Fremontii</i>	Silk-Tassel
HEAR-2	<i>Heteromeles arbutifolia</i>	Toyon
HOL-3	<i>Holodiscus species</i>	Cream Bush
KAPOM	<i>Kalmia polifolia</i> var. <i>microphylla</i>	Alpine Laurel (also American Laurel)
LEGLC1	<i>Ledum glandulosum</i> var. <i>californicum</i>	Labrador-Tea
LEDA	<i>Leucothoe Davisiae</i>	Sierra Laurel
LON	<i>Lonicera species</i>	Honeysuckle
PHLEC	<i>Philadelphus Lewisii</i> ssp. <i>californicus</i>	Mock-Orange
PRU-2	<i>Prunus species</i>	Stone Fruits
PREM	<i>Prunus emarginata</i>	Bitter Cherry
PRVID	<i>Prunus virginiana</i> var. <i>demissa</i>	Western Choke Cherry
PRSU-2	<i>Prunus subcordata</i>	Sierra Plum
PUTR	<i>Purshia tridentata</i>	Bitterbrush

TABLE II (cont.)

Shrub Codes Continued

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
QUE-1	Quercus species	Oak
QUDU-2	Quercus dumosa	Scrub Oak
QUVA	Quercus vaccinifolia	Huckleberry Oak
RHA-1	Rhamnus species	Cascara
RHCR	Rhamnus crocea	Redberry (also Buckthorn)
RHPU	Rhamnus Purshiana	Cascara Sagrada
RHRU	Rhamnus rubra	Sierra Coffeeberry
RHOC	Rhododendron occidentale	Western Azalea
RHDI	Rhus diversiloba	Poison Oak
RHTR	Rhus trilobata	Squaw Bush
RIB	Ribes species	Currant (also Gooseberry)
RIDI	Ribes divaricatum	
RINE	Ribes nevadense	Sierra Currant
RIRO	Ribes Roezlii	Sierra Gooseberry
ROS	Rosa species	Rose
RUB-2	Rubus species	Blackberry (also Raspberry, etc.)
RULE	Rubus leucodermis	Western Raspberry
RUPA-2	Rubus parviflorus	Thimbleberry
RUUR	Rubus ursinus	California Blackberry
SALI1	Salix species	Willow
SAM-2	Sambucus species	Elderberry
SACA-4	Sambucus caerulea	Blue Elderberry

TABLE II (cont.)

Shrub Codes Continued

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
SOR-4	Sorbus species	Mountain-Ash
SPI-3	Spiraea species	Spireae
STOFC	Styrax officinalis var. californica	California Storax
SYM-3	Symphoricarpos species	Snowberry
VAC-2	Vaccinium species	Huckleberry (also Bilberry or Blueberry)
VICA-3	Vitus californica	California Wild Grape

Non-living Component for Water Yield Related Information Place general comments on back

Date	Crew	Photo Plot	Time at Plot for Non-living Component
			Azimuth of Line (l°) _____

Point Index (10' apart) (No. W to E)	Line Photograph Role No./ Frame No. XX/XX	Surface at Point	Surface Layer Color (Munsell Notation)	Surface Layer Thickness (1/16")	Top Mineral Soil Horizon Color (Munsell)	Texture of Top Mineral Soil Horizon	Percent of 0"-3" Mineral Material Vol. >2mm(10%)
1	X						
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

Recording Form Key:

- 1) Surface at point
 B = bare mineral soil
 R(X) = rock
 S(X) = slash
 X = diameter of rock or slash
 to nearest 1/2"

- 2) Texture from soil in
 1 1/2 - 2 inch top soil
 mineral horizon
 0 = fragmental; stones
 predominate
 1 = coarse-textured; sandy
 2 = moderately coarse;
 sandy loams
 3 = medium-textured; loam,
 silt loam
 3S = silt
 4 = moderately fine; clay
 loam, sandy clay loam,
 silty clay loam
 5 = fine-textured; clay,
 silty clay, sandy clay

Modifiers:

G = gravelly, rock 2mm-3"
 C = cobbly, rock >3"-10"

3) Bedrock type

AI = acid igneous
 BI = basic igneous
 UBI = ultrabasic igneous
 MI = meta-igneous
 S = sedimentary
 MS = meta-sedimentary

Interval a-b	% of Line with Exposed Mineral Soil (10%)	% of Line Covered by Rock (10 %)	% of Line Covered by Dead Organic Matter >1/4" (10%)
1-2			
2-3			
3-4			
4-5			
5-6			
6-7			
7-8			
8-9			
9-10			
10-11			

Slope (1%) _____ Aspect _____


Microrelief Over Line(circle one):
 smooth, rolling, gullied, hummocky
 (mounding), other _____

Where Soil Profile Exposed
 Please Note (nearest 1/2 inch)
 1) Rooting depth _____
 2) Depth to water impervious layer _____
 3) Depth from top of mineral
 soil to bedrock _____
 4) Bedrock type _____

FIELD SHEET FOR RECORDING SOIL CHARACTERISTICS

No. _____

Soil Type _____
 Location _____
 Geographical Landscape _____
 Elevation _____ Slope _____ Aspect _____ Erosion _____
 Groundwater _____ Drainage _____ Alkali _____
 Mode of Formation _____ Parent Material _____
 Climate _____
 Natural Cover _____ Soil Region _____
 Profile Group _____ Higher Categories _____
 Genetically Related Soil Series _____

PROFILE SKETCH	COLOR	TEXTURE	STRUC- TURE	CONSISTENCE	REAC- TION	MISC: Roots, Pores, Clay films, Concretions
						

Natural Land Division _____
 Soil Rating (Storie index) _____ Soil Grade _____
 Land Use Capability Unit _____
 Present Use _____
 Suitability: Irrigated Crops _____ Range _____
 Nonirrigated Crops _____ Timber _____
 Soil Management _____
 Remarks _____

Date	Crew	Photo Plot	Time at Plot for Living Component
------	------	------------	-----------------------------------

A. Trees Having Largest Main Stem dbh Greater Than or Equal to 5.5 Inches

[illegible]

2b-164

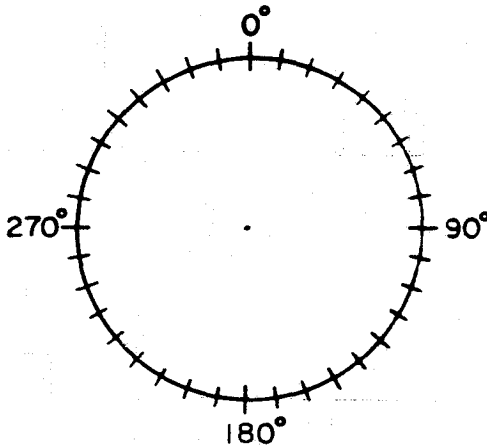
B. Trees Having Largest Main Stem dbh Less Than 5.5 Inches And Greater Than 6 Feet Tall.

[illegible]

A circular scale with degree markings at 0°, 90°, 180°, and 270°. The scale is marked with small tick marks every 10 degrees, and larger tick marks every 30 degrees. The 0° mark is at the top, 90° is on the right, 180° is at the bottom, and 270° is on the left.

2b-165

C. Trees Having dbh Less Than 5.5 Inches And 6 Feet To 2 Feet Tall Inclusive.

Index No./ Species Code	H ₁ (Tree Top)	H ₃ (Crown Bottom)	D ₁ (Trunk Midpoint)	Age for Conifers	Horizontal Foliar Density (% Background Obscured by Leaves)	Vertical Foliar Density	Diagram for Crown Area at Maximum Perimeter
XX/XXXX	(1/2') XX.X	(1/2') XX.X	(0.1') XX.X	(1 Year) XX	(10%) XX	(10%) XX	

2b-166

D. Trees Having dbh
Less Than 5.5 Inches
And Less Than
2 Feet Tall.

Species Code	Total No. of Individuals	Total Cumulative Crown Area as a Percent of the 0.01 Ac Plot Area (5%) XX
XXXX	XXX	
X X		
X X		
X X		
F. Herbaceous Vegetation	Total Cumulative Crown Area as a % of 0.01Ac Plot (5%) XX	
Component		
Grass-like		
Forb		
Fern		

APPENDIX IV
PROCEDURE FOR MEASURING SECONDARY SAMPLING
UNIT PHOTO PLOTS FOR WATER
LOSS ESTIMATION

David Marc Huston

APPENDIX IV: PROCEDURE FOR MEASURING SECONDARY SAMPLING UNIT PHOTO PLOTS FOR WATER LOSS ESTIMATION

1. INTRODUCTION

The secondary sampling unit discussed in section 2.110b contains information which is used to refine estimates of evapotranspiration made from the primary sampling unit. Some of the data from the SSU is in the form of large scale aerial photographs. The photo interpreter's task is to identify and quantify on these large scale photographs various features of the living and non living component in and about .01 acre plots selected by probability sampling.

The following sections describe the methods that the photo interpreter will follow to measure and describe the .01 acre plots.

The ensuing methodologies are based on the information that field crews extracted from .01 acre plots in the Spanish Creek Watershed in August, 1974. Where applicable the information sought by the photo interpreter is much the same as the information collected by the field crews.

The photographs used to develop these methodologies were obtained from five flight lines over the Spanish Creek Watershed. Each line was flown in April, May, and August. The plane was equipped with two 35mm cameras, one with a 24mm lens and the other with a 200mm lens, which contained Kodacolor II film. The cameras were synchronized so that the camera with the telephoto lens would take 3 frames for each frame taken through the wide angle lens. Therefore, each stereo triplet from the telephoto was located at the center of the wide angle photo.

Corresponding photographic products consisted of wide angle stereo pairs and telephoto triplets in 3R format ($4\frac{1}{2} \times 3\frac{3}{4}$ ") and 7" x 10" stereo pairs made from telephoto negatives. U.S. Geological Survey topographic maps and small scale 9"x9" highflight transparencies were also used. The approximate location of each of the wide angle photo centers were plotted on the USGS maps.

11. Photo Interpretation Tools

The photo interpreter will need the following tools:

1. mirror stereoscope
2. 2-4 power Abrams stereoscope
3. rulers, to $\frac{1''}{100}$ detail, or metric equivalent
4. point marker
5. light table
6. ink pen
7. dot grids (1 mm spacing),
8. protractor
9. parallax bar
10. stereo slope comparator
11. clear acetate sheets

III. Non-Living Component, Plot Data

A. Fill in the information requested at the top of Sheet NL2.

B. Plot Data for Sheet NL2

1. Using an appropriate (1 mm spacing), randomly located dot grid over the photo plot, count the number of dots falling on snow (excluding snow on the canopy cover), rock, and bare mineral soil within the photo plot for points where the ground is visible. Record these measurements on lines 5 - 7 as a fraction: the numerator is the number of dots falling on the item of interest and the denominator is the total number of ground visible photo plot dots. On line 8 record the number of dots falling on snow including both canopy and ground locations. On line 9 record the total number of dots falling in the photo plot.

2. Measure and determine the pattern, the direction, and the number, average length and width of cracks and fissures in areas of exposed bedrock. Record these measurements on lines 10a, 10b and 10c.

3. Take Munsell readings at these locations when the ground surface is visible and sunlit:

Azimuth	Distance from Plot Center
0°	- 1.00 X R, .75 X R, .50 X R, .25 X R
90°	- 1.00 X R, .75 X R, .50 X R, .25 X R
180°	- 1.00 X R, .75 X R, .50 X R, .25 X R
270°	- 1.00 X R, .75 X R, .50 X R, .25 X R

Record these readings in Table NL2 1.

4. General comments: describe the landform characteristics seen in the wide angle photo surrounding the photo plot based on the descriptions in Table 3.

IV. Non-Living Component, Line Data

A. Fill in the information requested at the top of Sheet NL1.

B. Line Data for Sheet NL1.

1. Locate the prepunched photo center of the middle large scale 3R stereo triplet. Find the corresponding point on the 7" x 10" stereo pair enlargement and the small scale 3R (wide angle) photo. Mark these locations with a point pricking needle. A point pricking needle is used as measurements to be made are critical and should be unaffected by the size of the point.
2. Locate and code the plot center on a USGS topographical map using the largest scale map available. Record the elevation of the plot center on line 5.
3. Determine the scale of the 3R wide angle, the 3R telephotos, and the 7" x 10" enlargements. Record the scale of each in lines 7, 8, and 9.

Factors that must be shown are:

plane's altitude - from Table 1. (Record on line 6)

plot center elevation - determined in step 2 above.

focal length:

wide angle lens = 24 mm = 0.94"

telephoto lens = 200 mm = 7.87"

all units must be the same

a 3R print (from a 35 mm negative) increases scale by a factor of 3.40 (this figure should be derived)

a 7" x 10" print increases the scale of a 35 mm negative by a factor

of 8.42 (this figure should be derived as the amount of enlargement during processing may not be consistent).

$$\text{scale} = \frac{\text{camera focal length}}{\text{plane's altitude above ground}}$$

4. Draw a true north-south line through the plot center. True north (or azimuth 0°) is found after a line of true direction is found. The line of true direction may be obtained by taking the azimuth reading of a line drawn through two points which can be located on both the USGS map and the wide angle or supporting high-flight photos. True north is determined by offsetting from this line the appropriate number of degrees.
5. Draw a circle about the plot center which encloses an area of .01 acre. This is the photo plot. On the ground the radius of a .01 acre circle is 11.78' or 141.36'. The radius of a circle on the photographs is:

$$R = \frac{141.36}{\text{scale (in inches)}}$$

The circle should be drawn so that the inner edge of the ink line is distance 'R' from the plot center. Record the radius of the circle on line 10.

6. The azimuth of a line to be drawn through the plot center is located along a topographic contour running through the plot center.

Record the azimuth in relation to the north-south line determined in step 4 on line 11. Ten points are to be located and marked along the azimuth line, the plot center is point #6. The distance between each point, 10' on the ground, is:

$$D = \frac{120''}{\text{scale (in inches)}} \quad \text{on the photo}$$

Record the calculated D value on line 12.

The points are enumerated 1 to 11, with #1 in the azimuth hemisphere to the west (180° to <360°) of the plot center point (point #6).

7. When crown canopy and shadow conditions permit, the ground cover at each of the 11 points should be described as either rock, slash, snow, or bare soil. Record this information in Column A. If the ground isn't visible, enter the code for either shade or plant cover.

8. Munsell soil color readings¹ should be taken at all sunlit points. Munsell readings are taken by laying the appropriate color chip over the area to be measured. The light source, angle of light source, and distance to the light source used to illuminate the photos should be kept constant and recorded. Suggested constants are:

angle of light - 45°

wattage of light - 100 watts

distance, bulb tip to measured area - 1 foot

Record these readings in Column B.

¹Munsell Soil Color Charts - Munsell Products, Macbeth Color and Photometry Division of Kolomorgen Corp., Baltimore, Maryland. 1973.

9. Measurements of the ground cover characteristics between two consecutive points are to be expressed as a percentage of the distance between the two points. Percents of bare mineral soil, rock, slash, and snow between two consecutive points should be determined by measurement if the ground can be seen. Measure the percent shadow or plant cover between each two points. Take a Munsell reading between consecutive points on sunlit ground. Record these measurements in Columns C - H.

10. Record the average aspect (to the nearest degree) for the photo plot on line 13. Aspect is the direction that a viewer looking downhill faces, or geometrically, aspect is the azimuth direction of a line perpendicular to a plane paralleling the average ground surface.

11. Determine the average slope of the photo plot with a stereo plot comparator. Record this figure on line 14.

12. General Characteristics. Comment on microrelief and erosional features described in Table 2.

V. Living Component. Tree Growth Forms (woody shrubs and herbaceous, vegetation excluded)

A. Fill in the information requested at the top of Sheet L1.

B. Photo Plot Data for Sheet L1

1. For each tree whose main stem and/or crown area falls within the .01 acre plot perform the following. For trees very near the photo center appearing nearly vertical, locate and mark the estimated true planimetric position of the tree trunk-ground interface point. This point may be approximated by the location of the tree crown apex. If trees don't appear vertical due to radial or relief displacement and the trunk-ground interface isn't visible under the stereoscope due to shading or plant cover, then estimate the location of the trunk-ground interface point and mark that point.
2. Identify each tree by species according to the keys and environmental information in Table 4. Identify and index each tree in the following manner. Give each tree dealt with an index number starting at one and continuing as 1, 2, 3 . . . Indexing starts with the tree whose stem is closest to zero azimuth and proceeds clockwise. Enter in Column A the index number used for each tree. Then place a "slash" mark and give the species code from Appendix 5. If the identity of a tree cannot be determined than use the code XXXC for conifer and the code XXXH for hardwood. Make another "slash" and enter the azimuth which runs through the trunk-ground interface point relative to the plot center.

3. Measure the distance between each of the points located in step 1 (the trunk-ground interface points) and the plot center. Record these measurements in Column B and convert to ground distance.
4. Measure the distance from the plot center to the bulge point for each tree on a line from the plot center to the trunk-ground interface point. Record these measurements in Column D and convert to ground distance.
5. Measure the crown diameter of each tree at its widest and narrowest points. Record these measurements in Column F and Column G and convert these figures to ground distance.
6. Measure the height of each tree with a parallax bar. Record these measurements in Column J.
7. Measure the height of the bulge point of each tree with a parallax bar. Record these measurements in Column K.
8. Measure the height of the crown bottom of each tree with a parallax bar. Record these measurements in Column L.
9. Estimate the canopy area of each tree in relation to the .01 acre plot area. Proceed by drawing each tree crown perimeter, and the plot circle, on an acetate overlay. Randomly locate (by a slight tossing motion) an appropriate density (1 mm spacing) dot grid over this overlay. Non-permanently, tape the dot grid to the overlay. The dot grid must cover the plot circle and all

crowns delineated on the overlay. Count the total number of dots falling within each tree's crown perimeter (including any portion that may be outside the plot). Record this information in Column M as the numerator of a fraction: the denominator of this fraction is determined by counting the number of dots that fall on the portion of the tree crown that is inside the photo plot. When dot counting the inclusion or exclusion of dots falling on the crown boundary is decided by coin flipping. "Heads" decides dot inclusion and "tails" decides dot exclusion.

10. Without moving the dot grid, count the total number of dots falling in the photo plot. Record this figure on line 5.

11. Without moving the dot grid, count the number of dots on the randomly located grid covering the photo plot which fall on the portions of the trees measured in this section which are within the plot circle. Record this figure on line 6.

12. Without moving the dot grid, count the number of dots falling on any leaf surface within the photo plot circle. Record this figure on line 7.

13. Describe the physiological state for each tree, referring to the description in Table 6. Record this information in Column N.

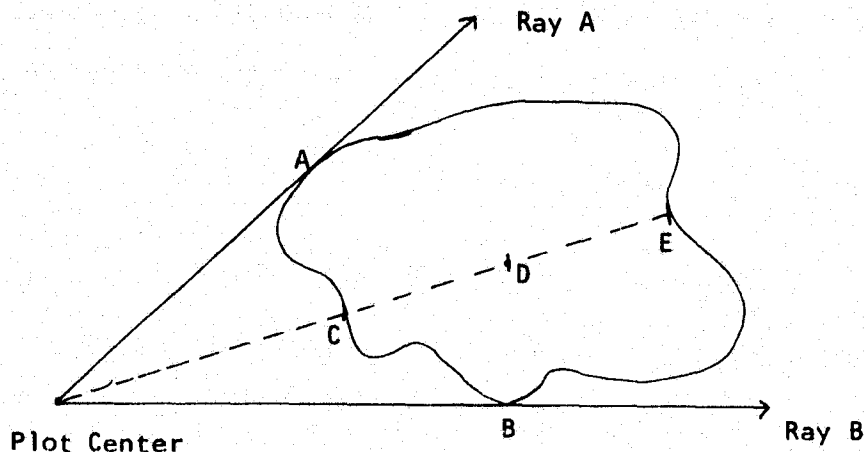
VI. Living Component - Woody Shrubs and Herbaceous Vegetation

A. Fill in the information requested at the top of Sheet L2.

B. Photo Plot Data for Sheet L2.

1. Mark the center of the shrub clones whose crowns fall in the .01 acre plot. Give each shrub clone dealt with an index number starting at one and continuing as 1, 2, 3, . . . Indexing starts with the clone whose center is closest to zero azimuth and proceeds clockwise. Enter the index number for each clone in Column A. Then place a "slash" mark and enter the species or genus code applicable (found in Table 5) if the clone can be identified. If the shrub clone can't be identified denote whether the clone is evergreen or deciduous. If evergreen write XXXE. If deciduous, write XXXD. If this information can't be determined write XXXU.

2. Take azimuth readings on two rays from the plot center that are tangent to the widest extent of the clone within the photo plot. Measure the distance from the plot center to the points on the clone tangent to the two rays. Also measure the nearest distance and farthest distance of the shrub clone on a line from the plot center, through the center of the clone marked in step 1 above.



Record this data in Columns C and E.

3. Estimate the height of the shrub clone in relation to a relatively shorter measured tree coded on Sheet L1. Record this figure in Column G.
4. Describe the physiological state of each shrub clone. Refer to Appendix 6 for the appropriate descriptions. Record these measurements in Column H.
5. Randomly locate (by a slight tossing motion) the dot grid over the photo plot. Non-permanently tape the dot grid to the photo. Count the number of dots falling on any shrub clone leaf surface within the photo plot circle. Record this figure on line 5.
6. Without moving the dot grid and in the same manner described in step 5 above, count the number of dots falling upon grasses, ferns, and forbs within the photo plot. Record this figure on line 6.
7. Without moving the dot grid, count the total number of dots falling within the photo plot. Record this figure on line 7.

Table 1: Pilot's Data for Flight Lines

Date	Flight Line No.	Description	Approx. Terrain Elev.	Flying Altitude Above MSL (+ 100')
April 4, 1974	1	Silver Lake	4700'	7200'
	2	Gold Lake	4700'	7150'
	3	Schneider Creek	4900'	7350'
	4	South of Quincy	5500'	7950'
	5	Squirrel Creek	5500'	8000'
May 9, 1974	1	Silver Lake	4700'	7100-7200'
	2	Gold Lake	4700'	7050-7150'
	3	Schneider Creek	4900'	7400'
	4	South of Quincy	5500'	7850-7900'
	5	Squirrel Creek	5500'	8000'
May 30, 1974	1	Silver Lake	4700'	7300'
	2	Gold Lake	4700'	7250'
	3	Schneider Creek	4900'	7300'
	4	South of Quincy	5500'	7550'
	5	Squirrel Creek	5500'	8000'
August 21, 1974	1	Silver Lake	4700'	7250'
	2	Gold Lake	4700'	7100'
	3	Schneider Creek	4900'	7400'
	4	South of Quincy	5500'	8000'
	5	Squirrel Creek	5500'	8000'

Table 2: Microrelief and Erosional Feature Description

There are five general types of erosional features that the photo interpreter may see on large scale imagery. They are due to the following erosional processes.

1. sheet erosion (fluvial)
2. wind erosion (eolian)
3. rilling (fluvial)
4. gullyng (fluvial)
5. mass wastage (mass wasting)

The first two, sheet erosion and wind erosion, are more likely to occur and be identified in arid and semi-arid areas. The latter three, rilling, gullyng, and mass wastage, may be observed in humid areas such as the Spanish Creek Watershed.

gully A gully is defined as an eroded trench greater than 2-3 feet in depth resulting from water-cutting force aided soil erosion. Recently formed gullies can be differentiated from summer dry stream beds by the fact that there is only sparse woody riparian vegetation along gully banks.

rill A rill is defined as a shallow trench less than one foot in depth resulting from water-cutting force aided soil erosion.

mass wastage Mass wastage can take the form of landslides or slumps.

Mass wastage can be revealed by low pressure mounds and ridges along a slope, by twisted tree trunks and the curling of soil material over road beds.

Table 3: Description of Landform Characteristics¹

<u>alluvial fan</u>	a cone-shaped deposit of alluvium made by a stream where it runs out onto a level plain and meets a slower stream. The fans generally form where streams issue from mountains upon the lowland.
<u>alluvial plain</u>	A plain resulting from the deposition of alluvium by water.
<u>arete</u>	An acute and rugged crest of a mountain range, or a subsidiary ridge between two mountains or of a mountain spur, such as that between two cirques.
<u>canyon</u>	A steep-walled chasm, gorge or ravine; a channel cut by running water in the surface of the earth, the sides of which are composed of cliffs or series of cliffs rising from its bed.
<u>cirque</u>	A deep steep-walled recess in a mountain, caused by glacial erosion.
<u>col</u>	A saddle or gap across a ridge and between two peaks; also, in a valley in which streams flow both ways from a divide, that part of the valley at the divide, especially if the valley slopes rather steeply away from the divide.
<u>hill</u>	In general, the term hill is properly restricted to more or less abrupt changes in elevations of less than 1,000 feet, all altitudes exceeding this being mountains.
<u>moraine</u>	Drift, deposited chiefly by direct glacial action, and having constructional topography independent of control by the surface on which the drift lies.

mountain

A tract of land considerably elevated above the adjacent country. The term is usually applied to relatively abrupt elevation changes of more than 2,000 feet.

plain

A region of general uniform slope, comparatively level, of considerable extent, and not broken by marked elevations or depressions.

ravine

A depression worn out by running water, larger than a gully and smaller than a valley.

talus

A collection of fallen disintegrated material which has formed a slope at the foot of a steeper declivity.

tarn

A small mountain lake or pool, especially one that occupies an ice gouged basin on the floor of a cirque.

**Table 4 - Tree Species Keys, Photographic
Examples and Environmental Description**

This table is comprised of the following components which will aid the interpreter in the identification of tree species in the Spanish Creek Watershed:

1. A summary of identifying characteristics to forest species which includes:
 - a) average heights for mature trees.
 - b) the color of trees on Kodacolor II prints.
 - c) a crown description
 - d) a crown margin description
 - e) branch characteristic description
 - f) listing of soils on which the tree occurs.
2. An ecological summary and aerial description of tree species which describes:
 - a) tolerance to shade
 - b) occurrence with other species
 - c) a description of aerial characteristics (from Lauer, 1966)
3. A dichotomous key developed by Lauer, (1966)
4. Photographic examples in 3R stereo pairs with accompanying written descriptions

The photo interpreter should familiarize himself/herself with the preceding identification aids. Most mature trees can be identified by their morphological characteristics on the large scale photos. When confusion exists, as between white fir and red fir and between ponderosa pine and Jeffry pine, other plot information such as elevation, aspect, and ecological characteristics should enable the interpreter to make the differentiation with confidence.

Summary of Identifying Characteristics of Forest Species in the Spanish Creek Watershed¹

Species	Tree Height	Color on Kodacolor II Prints	Crown Description	Crown Margin	Branch Characteristics	Soils
<u>Abies concolor</u>	60 - 180'	whitish green	<u>mature</u> irregular, round topped; <u>live</u> crown to ground in open stands	crenate	short stiff branches, <u>mature trees</u> lower and middle crown branches droop, upper stay upright	deep, rich, moist loams, frequent among disintegrating granite
<u>Abies magnifica</u>	60 - 200'	whitish green	<u>mature</u> short, narrow, round topped; brittle top often broken; <u>young</u> extend to ground	crenate	<u>mature</u> branches droop except at crown top	moist, porous
<u>Calocedrus decurrens</u>	50 - 150'	yellow green	<u>mature</u> open, irregular; <u>young</u> narrow, pointed, extends to ground	denticulate	dense tufts of foliage	deep, acid loams
<u>Juniperus occidentalis</u>	15 - 30'	yellow green	round topped, open crown	dentate	branches large, spreading foliage at end of branches, leaving interior stems foliage free	similar to <u>Pinus jeffreyi</u>
<u>Pinus lambertiana</u>	60 - 200'	whitish green	<u>mature</u> flat topped <u>young</u> open & narrow	parted	<u>mature</u> well spaced wide spreading	well drained sandy loams
<u>Pinus jeffreyi</u>	125 - 140'	yellow green	long, narrow crown	denticulate	branches less stout and angled than <u>Pinus ponderosa</u>	well drained loose, coarse, sandy, or gravelly loams

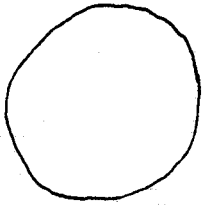
<u>Pinus ponderosa</u>	125 - 140'	yellow green	long, narrow crown	denticulate	short, pendulous branches which are upturned at ends	well drained loams
<u>Pseudotsuga menziesii</u>	70 - 250'	blue green	mature rounded or flattened; young broad, sharp pyramid	dentate	numerous long side hanging branchlets	loose, well drained
<u>Quercus kelloggii</u>	50 - 75'	light green	irregular, broad, lobed open rounded			dry loams

* See Figure 1 for sketches of crown margins

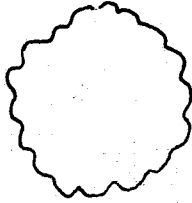
1. Lauer, Donald T. The Feasibility of Identifying Forest Species and Delineating Major Timber Types in California by Means of High Altitude Small Scale Aerial Photography. School of Forestry, University of California, Berkeley, California. September 30, 1966

CROWN MARGIN

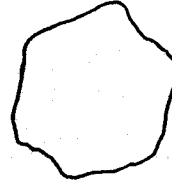
ENTIRE - margin even,
not toothed



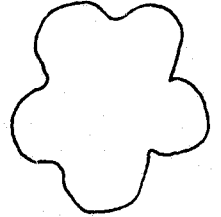
CRENATE - margin notched
with rounded teeth



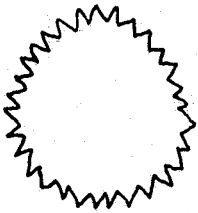
SINUATE - margin
wavy



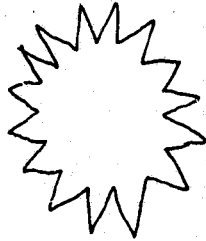
LOBED - margin
deeply rounded



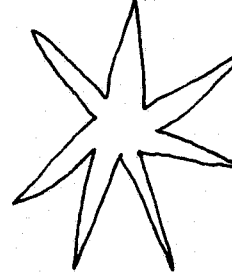
DENTICULATE - Margin
minutely sawtoothed



DENTATE - margin
deeply sawtoothed



PARTED - margin deeply
recessed, star-shaped



CROWN APEX

TRUNCATE - apex cut
off sharply



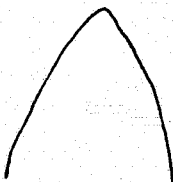
ROUNDED - apex
broadly rounded



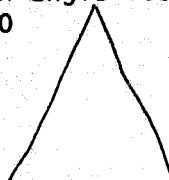
OBTUSE - apex
bluntly rounded



OVATE - apex
bluntly pointed



ACUTE - apex
termination in
an angle less than
90



ACUMINATE - apex
gradually diminishing

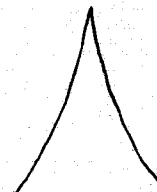


Figure 1: Schematic drawings of tree morphology as seen on aerial photography.

Ecological Summary and Aerial Description of Plumas County Forest Species

1,2

1,2

3

Species	Tolerance to Shade	Occurrence	Aerial Characteristics
<u>Abies concolor</u>	very, more so than associated species, slow progress under heavy shade	moderate elevations (4000-7000'); N&E aspects; w/ PIPO, PILO, CADE ABMA	A 60 to 200 foot evergreen tree with a straight trunk. Whorled branches form a cylinder-shaped crown with a very pointed top. A heavy cone crop in the top of the tree crown is often discernible on fall photography.
<u>Abies magnifica</u>	very moderately tolerant, rarely in subordinate positions in even aged stands	above 5000' in Plumas, to timber line; N&E aspects; nearly pure stands; w/PILA, PSME and sometimes ABCU, PIPO.	A 60 to 200 foot evergreen tree with a straight trunk. Whorled branches form a cylinder-shaped crown with a very pointed tip which is very brittle and often broken. A heavy cone crop in the top of the tree crown is often discernible on fall photography.
<u>Calocedrus decurrens</u>	more tolerant than PILO, PIPO, PSUE; subordinate due to slower growth and greater tolerance	E rather than W aspect; w/PILO, PIPO	A 50 to 150 foot tree with a tapering trunk from a thick base. Spreading and slightly drooping branches form a broadly rounded to obtuse crown apex. Difficult to separate from ponderosa pine.
<u>Juniperus occidentalis</u>	intolerant	Similar to <u>Pinus jeffreyi</u>	A 15 to 30 foot evergreen tree with large spreading branches and open crown. A distinct yellow-green color, interior branch stems are devoid of vegetation.
<u>Pinus lambertiana</u>	very intolerant when mature; requires partial shade when young	N slopes, benches, ravines; S&W slopes at higher altitudes; w/ PIPO, CADE, PSME, ABCO, ABMA; never in pure stands	A 60 to 200 foot evergreen with a straight trunk. Huge branches spread outward horizontally and often form a flat-topped crown. The deeply parted crown is the primary characteristic discernible on aerial photos.

Pinus
jeffreyisimilar to Pinus
ponderosaon dry, Eastern slopes
5200 to 9000' elevation
w/ PIPO, ABMA, CADE,
JUOCsimilar to Pinus ponderosa but with a
larger more symmetrical crownPinus
ponderosagreater than 20' needs
unbroken light; trees of
this species in mature
stands rarely touch crownsdry and moist slopes; pure &
mixed stands; w/ PILO, CADE,
PSME, ABCO; brushy ground
cover when youngA 60 to 200 foot evergreen tree with a
straight trunk. Spreading and slightly
drooping branches form a broadly rounded
to obtuse crown apex. A slightly brownish
cast due to needle dieback can be detected
in fall photography. Separated from
incense cedar only by its superior height,
occurrence in pure stands, or occurrence
on drier sites.Pseudotsuga
menziesiimoderately tolerant:
more than PIPO, PILA,
but less than ABCO, CADEprefers N than S aspect;
at higher elevations:
E than W
S than N aspectsA 70 to 250 foot evergreen tree with
a straight trunk. Irregular whorled
branches spread horizontally with pen-
dulous branchlets forming a deeply saw-
toothed crown margin.Quercus
kelloggiimoderate when young;
tolerance subordinate
to that of PIPOslopes, valleys, benches,
w/ PSME, PIPO, CADEA 30 to 80 foot deciduous tree with stout
spreading branches forming a broad round
topped crown. The foliage on each branch
gives the crown margin a lobed or billowy
appearance. Its fall color appears yellow
to yellow-green.

1. Munz, Phillip A. A California Flora and Supplement University of California Press, Berkeley and Los Angeles, California. 1968
2. Sudworth, George B. Forest Trees of the Pacific Slope, Dover Publications, Inc. New York, New York, 1967.
3. Lauer, Donald T. (ibid)

DICHOTOMOUS PHOTO INTERPRETATION KEY FOR
FOURTEEN CALIFORNIA FOREST SPECIES FOUND TO OCCUR
IN THE BUCKS LAKE-MEADOW VALLEY AREA (MIXED CONIFER FOREST TYPE);

1. Tall (100 feet) evergreen trees with bluntly rounded (obtuse)
to pointed (acute) crown apices 2
1. Medium tall (100 feet) deciduous trees with broadly rounded
crown apices 8
 2. Crown apices are sharply pointed 3
 2. Crown apices are bluntly rounded 4
3. Mature stands are whitish-green on aerial Kodacolor II prints.
Cone crop is often discernible in the Fall . . . Abies concolor
3. Mature stands are whitish-green on aerial Kodacolor II prints.
Cone crop is often discernible in the Fall. Generally is found at
higher elevations Abies magnifica
4. Trees often taller than 100 feet. Mature stands are
yellow-green or whitish-green on aerial Kodacolor II prints.
Generally is found on a variety of well-drained soils 5
4. Trees rarely taller than 100 feet. Mature stands are
brownish-green on aerial Kodacolor II prints. Generally
is found on wet flats or poorly drained soils Pinus contorta
5. Mature stands are yellow-green or blue-green on aerial
color prints. Crown margins are minutely sawtoothed
(denticulate) or deeply sawtoothed (dentate) 6
5. Mature trees are whitish-green on aerial Kodacolor II prints
Crown margins are deeply parted Pinus lambertiana
6. Mature stands are yellow-green on aerial Kodacolor II prints.
Crown margins are minutely sawtoothed (denticulate) 7
6. Mature stands are blue-green on aerial Kodacolor II prints.
Crown margins are deeply sawtoothed (dentate) Pseudotsuga menziesii

7. Mature stands rarely occur on serpentine soils Pinus ponderosa
7. Mature stands often occur on serpentine soils . . . Libocedrus decurrens
8. Trees are non-riparian; genearily occuring
on dry, well-drained soils 9
8. Trees are riparian; generally occuring on moist
alluvial soils 10
9. Trees often taller than 40 feet. Mature stands are bright yellow
or brownish-red during fall color change Quercus kelloggii
9. Trees rarely taller than 40 feet. Mature stands are
bright-red during fall color change Cornus nuttallii
10. Trees often taller than 40 feet 11
10. Trees rarely taller than 40 feet Alnus tenuifolia
and Salix sp.
11. Crown apexes are broadly rounded and crown margins are deeply
rounded (lobed) Acer macrophyllum
11. Crown apexes are bluntly rounded (obtuse) and crown margins
are notched with rounded teeth (crenate) Populus tremuloides

Height and Occurrence of Several Shrubs of the Spanish Creek Watershed

Species	Height ^{1,2}	Occurrence ^{1,2}
<u>Amelanchier</u> <u>pallida</u>	3 - 15'	2500' to 9000' elevation; moist habitats; dry, gravelly and rocky slopes; with ponderosa & lodgepole; often in large thickets; deciduous
<u>Ceanothus</u> <u>cordulatus</u>	2 - 6'	3500' to 9000' elevation; rocky ridges and pine habitats; up to 12' diameter; can form continuous ground cover; evergreen
<u>Ceanothus</u> <u>prostratus</u>	2 - 6"	2100 to 7800' to 8' diameter; usually grows under pines, mixed conifer; forms dense mats; evergreen
<u>Chrysolepis</u> <u>sempervirens</u>	1 - 8'	1500' to 12,500' elevation; thickets on dry mountain ridges; rocky places of open forests; evergreen
<u>Cornus</u> <u>species</u>	4 - 15'	to 6000' elevation stream banks and moist flats deciduous
<u>Prunus</u> <u>emarginata</u>	3 - 18'	4000' to 8000' elevation; extensive thickets on moist slopes, stream beds; deciduous
<u>Quercus</u> <u>dumosa</u>	2 - 9'	western, middle elevation slopes of Sierra; evergreen
<u>Quercus</u> <u>vaccinifolia</u>	1 - 4'	5000' to 10,000' elevation; mountain ridges, rocky situations; mainly west aspect; often prostrate; evergreen
<u>Ribes</u> <u>nevadense</u>	1 - 6'	3500' to 8500' elevation; canyons, moist slopes; deciduous

Rhamnus
purshiana

6 - 36'

along creek banks, seepages;
deciduous

Rubus
parviflorus

3 - 6'

0 to 9000' elevation; near water
courses; deciduous

Symphoricarpos
species

2 - 6'

5000' - 10,000' elevation; deciduous

1. Munz, Phillip A. (ibid)

2. McMinn, Howard E. An Illustrated Manual of California Shrubs University of California Press,
Berkeley, Los Angeles, California, 1970.

TABLE 5 - Tree and Shrub Codes

I. Tree Codes

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
ABCO	<i>Abies concolor</i>	White Fir
ABMA-2	<i>Abies magnifica</i>	Red Fir
ACMA	<i>Acer macrophyllum</i>	Broadleaf Maple
ALN-2	<i>Alnus species</i>	Alder
ALRH	<i>Alnus rhombifolia</i>	White Alder
ARME-3	<i>Arbutus menziesii</i>	Madrone
BEOC-2	<i>Betula occidentalis</i>	Water Birch
CADE	<i>Calocedrus decurrens</i>	Incense Cedar
FRA10	<i>Fraxinus species</i>	Ash
JUN-5	<i>Juniperus species</i>	Juniper
JUOC	<i>Juniperus occidentalis</i>	Sierra Juniper
LIDE-2	<i>Lithocarpus densiflora</i>	Tan-bark Oak
PIAL	<i>Pinus albicaulis</i>	Whitebark Pine
PIAT-1	<i>Pinus attenuata</i>	Knobcone Pine
PICOM	<i>Pinus contorta</i> var. <i>murrayana</i>	Lodgepole Pine
PIJE	<i>Pinus jeffreyi</i>	Jeffrey Pine
PILA	<i>Pinus lambertiana</i>	Sugar Pine
PIMO-2	<i>Pinus monophylla</i>	Piñon Pine
PIMO-3	<i>Pinus monticola</i>	Silver Pine (also Western White Pine)
PIPO	<i>Pinus ponderosa</i>	Ponderosa Pine (also Yellow Pine)
PISA-2	<i>Pinus sabiniana</i>	Digger Pine

Table 5 (cont.)

Tree Codes Continued

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
PLRA	Platanus racemosa	California Sycamore
PSME	Pseudotsuga menziesii	Douglas-fir
POFR-3	Populus fremontii	Fremont Cottonwood
POTR-3	Populus tremuloides	Quaking Aspen
POTR-4	Populus trichocarpa	Black Cottonwood
QUCH-2	Quercus chrysolepis	Canyon Oak (also Golden Oak)
QUKE	Quercus kelloggii	California Black Oak
QUWI	Quercus wislizenii	Interior Live Oak
TABR	Taxus brevifolia	California Yew
TOCA	Torreya californica	California Nutmeg
TSME	Tsuga mertensiana	Mountain Hemlock
UMCA	Umbellularia californica	California Laurel (also California Bay)

II, Shrub Codes

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
ACE-1	Acer species	Maple
ADFA	Adenostoma fasciculatum	Chamise
ALN-1	Alnus species	Alder
ALTE	Alnus tenuifolia	Mountain Alder
AMPA-2	Amelanchier pallida	Service Berry
ARC-5	Arctostaphylos species	Manzanita
ARMA-3	Arctostaphylos manzanita	Common Manzanita

Table 5 (cont.)

Shrub Codes Continued

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
ARME-2	Arctostaphylus Mewukka	Indian Manzanita
ARNE-2	Arctostaphylos nevadensis	Pinemat Manzanita
ARVI-3	Arctostaphylos viscida	Whiteleaf Manzanita
ART-5	Artemesia species	Sagebrush
ATR-3	Atriplex species	Saltbush
CAOC-2	Calycanthus occidentalis	Spice-Bush
CEA	Ceanothus species	California Lilac
CECO-2	Ceanothus cordulatus	Mountain Whitehorn
CECU-2	Ceanothus cuneatus	Buck Brush
CEIN-3	Ceanothus integerrimus	Deer Brush
CEJE	Ceanothus jepsonii	
CEPR	Ceanothus prostratus	Squaw Carpet
CEVE-3	Ceanothus velutinus	Tobacco Brush
CEOC	Cercis occidentalis	Redbud
CER-8	Cercocarpus species	Mountain-Mahogany
CHFO-2	Chamaebatia foliolosa	Kit-kit-dizze (also Mountain Misery or Bear Clover)
CHSE	Chrysolepsis sempervirens	Bush Chinquapin
CHR-9	Chrysothamnus species	Rabbit Brush
CLLI-2	Clematis ligusticifolia	Western Clematis
COR16	Cornus species	Dogwood
CONU-2	Cornus Nuttallii	Mountain Dogwood

Table 5 (cont.)

Shrub Codes Continued

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
QUE-1	Quercus species	Oak
QUDU-2	Quercus dumosa	Scrub Oak
QUVA	Quercus vaccinifolia	Huckleberry Oak
RHA-1	Rhamnus species	Cascara
RHCR	Rhamnus crocea	Redberry (also Buckthorn)
RHPU	Rhamnus Purshiana	Cascara Sagrada
RHRU	Rhamnus rubra	Sierra Coffeeberry
RHOC	Rhododendron occidentale	Western Azalea
RHDI	Rhus diversiloba	Poison Oak
RHTR	Rhus trilobata	Squaw Bush
RIB	Ribes species	Currant (also Gooseberry)
RIDI	Ribes divaricatum	
RINE	Ribes nevadense	Sierra Currant
RIRO	Ribes Roezlii	Sierra Gooseberry
ROS	Rosa species	Rose
RUB-2	Rubus species	Blackberry (also Raspberry, etc.)
RULE	Rubus leucodermis	Western Raspberry
RUPA-2	Rubus parviflorus	Thimbleberry
RUUR	Rubus ursinus	California Blackberry
SAL11	Salix species	Willow
SAM-2	Sambucus species	Elderberry
SACA-4	Sambucus caerulea	Blue Elderberry

Table 5 (cont.)

Shrub Codes Continued

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
COST-3	Cornus stolonifera	American Dogwood (also Creek Dogwood)
COCOC	Corylus cornuta var. californica	Hazelnut
CYSC-2	Cytisus scoparius	Scotch Broom
DERI	Dendromecon rigida	Bush Poppy
DIP	Diplacus species	Bush Monkey-Flower
ERCA-6	Eriodictyon californicum	Yerba Santa
ERI21	Eriophyllum species	Yarrow
GAFR	Garrya Fremontii	Silk-Tassel
HEAR-2	Heteromeles arbutifolia	Toyon
HOL-3	Holodiscus species	Cream Bush
KAPOM	Kalmia polifolia var. microphylla	Alpine Laurel (also American Laurel)
LEGLC1	Ledum glandulosum var. californicum	Labrador-Tea
LEDA	Leucothoe Davisiae	Sierra Laurel
LON	Lonicera species	Honeysuckle
PHLEC	Philadelphus Lewisii ssp. californicus	Mock-Orange
PRU-2	Prunus species	Stone Fruits
PREM	Prunus emarginata	Bitter Cherry
PRVID	Prunus virginiana var. demissa	Western Choke Cherry
PRSU-2	Prunus subcordata	Sierra Plum
PUTR	Purshia tridentata	Bitterbrush

Table 5 (cont.)

Shrub Codes Continued

<u>Code</u>	<u>Scientific Name</u>	<u>Common Name</u>
SOR-4	Sorbus species	Mountain-Ash
SPI-3	Spiraea species	Spireae
STOFC	Styrax officinalis var. californica	California Storax
SYM-3	Symphoricarpos species	Snowberry
VAC-2	Vaccinium species	Huckleberry (also Bilberry or Blueberry)
VICA-3	Vitus californica	California Wild Grape

Table 6

Description of Physiological State Conditions
Evident in Plants on Aerial Kodacolor II Prints

A. Conifers and Evergreens

1. cone crop - a cone crop is present and visible on conifers
2. new growth - a ring of new growth on conifers which shows up in contrast to the older foliage which is inward from the perimeter of the crown
3. dead - a conifer has no foliage and appears dead.
4. normal - the tree has no characteristics visible which indicate special phenological events.

B. Deciduous Trees and Shrubs

1. pre-foliage - in spring imagery there is no foliage apparent on the bare branches.
2. flowering - flowers are apparent.
3. foliage - plants have foliage in summer growing season.
4. autumn foliage - deciduous trees have turned to their fall colors.
5. post-foliage - in fall imagery there is no foliage apparent on bare branches.

Non-Living Component for Water Related Information from Photo Interpretation

- 1) Date 2) Photo Interpreter 3) Photo Plot No. 4) Date Flown
 5) Elevation of Photo Plot 6) Altitude of plane 7) Scale of 3R wideangle
 8) Scale of 3R telephoto 9) Scale of 7" x 10" enlargement 10) Radius of Circle(R)
 11) Azimuth of line (1°) 12) Photo distance between line points (D)
 13) Aspect (1°) 14) Slope (5%)

Point Index No. W to E	A Surface Point	B Munsell Color Notation	Interval a-b	C % of line covered with mineral soil	D % of line covered by rock	E % of line covered by snow	F % of line covered by slash	G % of line covered by plants, shade	H aver. Munsell color over line excluding plants, shade
1			1-2						
2			2-3						
3			3-4						
4			4-5						
5			5-6						
6			6-7						
7			7-8						
8			8-9						
9			9-10						
10			10-11						
11			11-12						

Recording Form Key:

- 1) Surface at Point
 B = bare mineral soil
 R = rock
 S = slash
 Sn = snow

- 11) Vision Obstructions
 NVSH = not visible, shade
 NVPC = not visible, plant cover

Place general comments on
back

Non-Living Component for Water Related Information from Photo Interpretation

1) Date _____ 2) Photo Interpreter _____ 3) Photo Plot No. _____ 4) Date Flown _____

Areal Extent of Ground Features within Plot

(based on portion of plot where ground surface is visible)

- 5) no. of bare, mineral soil dots/no. of ground visible dots _____
 6) no. of rock dots/no. of ground visible dots _____
 7) no. of snow dots/no. of ground visible dots _____
 8) no. of dots falling on both surface and plant canopy snow _____
 9) no. of dots falling within the photo plot _____
 10) Cracks and Fissures

- a) General pattern (circle the appropriate) parallel, dendritic, trellis, _____
 b) direction of cracks or fissures as a percent of the total number of
 cracks for the following azimuth classes: 315° - 45° _____, 45° - 135° _____,
 135° - 225° _____, 225° - 315° _____

- c) total number of cracks or fissures, and average length
 and width for the following azimuth classes: 315° - 45° No. = _____, L = _____, W = _____
 45° - 135° _____, _____, _____
 135° - 225° _____, _____, _____
 225° - 315° _____, _____, _____

Table NL2 1 - Munsell Readings

	1.00 X R	.75 X R	.50 X R	.25 X R
0°				
90				
180				
270				

Living Component Water Related Information from Photo Interpretation

A. Tree Growth Form. All trees, excluding woody shrubs and herbaceous vegetation, within the plot

1) Date _____ 2) Photo Interpreter _____ 3) Photo Plot No. _____ 4) Date Flown _____

A	B	C	D	E	F	G	H
Index No./ Species Code/ Azimuth	D ₁ Plot center to trunk ground interface distance on photo	D _{1-c} conversion to ground distance	D ₂ plot center to bulge point distance on photo	D _{2-c} conversion to ground	C max maximum crown diameter	C min minimum crown diameter on photo	C max-c conversion to ground distance
XX/XXXX/XXX	X.XX(.01")	XX.X	X.XX(.01")	XX.X	X.XX(.01")	X.XX(.01")	XX.X

5) total no. dots within photo plot _____

6) total no. dots falling on overstory
trees within photo plot _____7) total no. dots falling on any
leaf surface within plot _____

Physiological State Code

Evergreens

cc = cone crop

d = dead

ng = new growth apparent

n = normal appearance

Deciduous

pf = pre foliage

f = foliage

af = autumn foliage

pof = post foliage

n = flowering

CONTINUED ON NEXT PAGE

Living Component Water Related Information from Photo Interpretation

B. Woody Shrubs and Herbaceous Vegetation within the plot

1) Date _____ 2) Photo Interpreter _____ 3) Photo Plot No. _____ 4) Date Flown _____

A	B	C	D	E	F	G	H
Index No./ Species Code/	Azimuth reading to shrub extent	Da/b plot center to points a and b a/b	Da-C/b-c conversion to ground distance	Dc/d/e plot center to points cde X.XX/X.X/X.XX (.01")	Dc-c/d-c/e-c conversion to ground distance	H ₁ height of shrubs clone	physiological state (see code)
XX/XXXX/XX	XXX/XXX(.01")	X.XX/X.XX(.01")	XX.X/XX.X		XX.X/XX.X/XX.X	XX (2')	

Physiological State Code

5) no. of dots falling on shrub clones
within the photo plot _____6) no. of dots falling on grasses,
ferns, and forbes within
the photo plot _____7) no. of dots falling within
the photo plot _____Evergreens

cc = cone crop

d = dead

ng = new growth
apparentn = normal
appearanceDeciduous

pf = pre foliage

f = foliage

af = autumn foliage

pof = post foliage

fl = flowering

I	J	K	L	M	N
C min-c conversion to ground distance	(tree top) ± 5%	(bulge point) ± 5%	(crown bottom) ± 5%	dots in crown in in photo plot	physiological state (see code)
XX.X	XXX	XXX	XXX	XXX/XXX	

CHAPTER 3

WATER DEMAND STUDIES IN CENTRAL CALIFORNIA

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Chapter 3
Table of Contents

	<u>Page</u>
3.0 Introduction	3-1
3.01 Work Plan	3-1
3.02 Agency Contract	3-1
3.03 KCWA Hydrologic Model	3-4
3.10 Croplands Mapping	3-9
3.11 Introduction	3-9
3.12 Goal	3-10
3.13 Methodology	3-10
3.14 Results	3-12
3.15 Summary	3-22
3.20 Crop Identification	3-25
3.21 Introduction	3-25
3.22 Goal	3-26
3.23 Methodology	3-26
3.24 Crop Identification Application: Cotton	3-30
3.30 Water Demand Prediction	3-31
3.31 Introduction	3-31
3.32 Goal	3-31
3.33 Methodology and Results	
3.40 Cloud Cover Analysis	
3.41 Introduction	3-37
3.42 Goal	3-38
3.43 Methodology	3-38
3.44 Results	3-38
3.50 Salinity	3-41
3.51 Introduction	
3.52 Goal	3-43
3.53 Methodology	3-44
3.54 Interpretation and Compilation of a Salinity Damage Map	3-45

Table of Contents (cont.)

3.55 Salinity Prediction	3-50
3.60 Perched Water	3-58
3.61 Introduction	3-58
3.62 Goal	3-59
3.63 Methodology	3-60
3.64 Results	3-60
3.70 Image Processing	3-62
3.80 Future Work	3-63
3.90 Special Studies	3-64
3.91 Cropland Mapping and Crop Identification Techniques in Coastal Environments	3-64
3.92 Groundbasin Permeability Study	3-65
3.93 Detection of Waterlogged Soils	3-66
3.94 Oil Field Sump and Road Mapping	3-66
3.95 Forest Fire/Fuel Study	3-67

Chapter 3

WATER DEMAND STUDIES IN CENTRAL CALIFORNIA

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3.00 INTRODUCTION

Research activities conducted by the Geography Remote Sensing Unit (GRSU) for this reporting period include: (A) The development and analysis of remote sensing techniques for generating data as input to water demand models; (B) Comparison between conventional techniques and remote sensing techniques in terms of time, cost, and accuracy; and (C) Analysis of the economic impact resulting from changes in remote sensing water demand information.

During this reporting period, GRSU has focused a major portion of its research on the Kern County Water Agency (KCWA) hydrologic model; specifically our efforts have been directed toward four critical input parameters capable of being monitored by remote sensing techniques. These parameters are irrigated croplands, crop type, soil salinity, and perched water. Care has been taken to make our studies complementary to, rather than competitive with, those being conducted under this integrated project by our colleagues on the Riverside Campus of the University of California.

3.01 WORK PLAN

Figure 3-1 locates the test areas for the Santa Barbara and Riverside water demand studies. A listing of the tasks and the anticipated temporal framework within which they are being accomplished can be seen in Figure 3-2. With the remote sensing inputs to the KCWA hydrologic model identified, GRSU personnel have been concentrating their research activities on work items 4, 5, 6, and 7 listed in Figure 3-2. During the forthcoming period it is expected that the GRSU will expand its research in these areas as the remote sensing inputs to the KCWA model are analyzed and compared to conventionally derived data.

3.02 AGENCY CONTACT

Agency contacts during the earlier stages of this project were aimed primarily at establishing working relationships with those

UNIVERSITY OF CALIFORNIA WATER DEMAND STUDIES

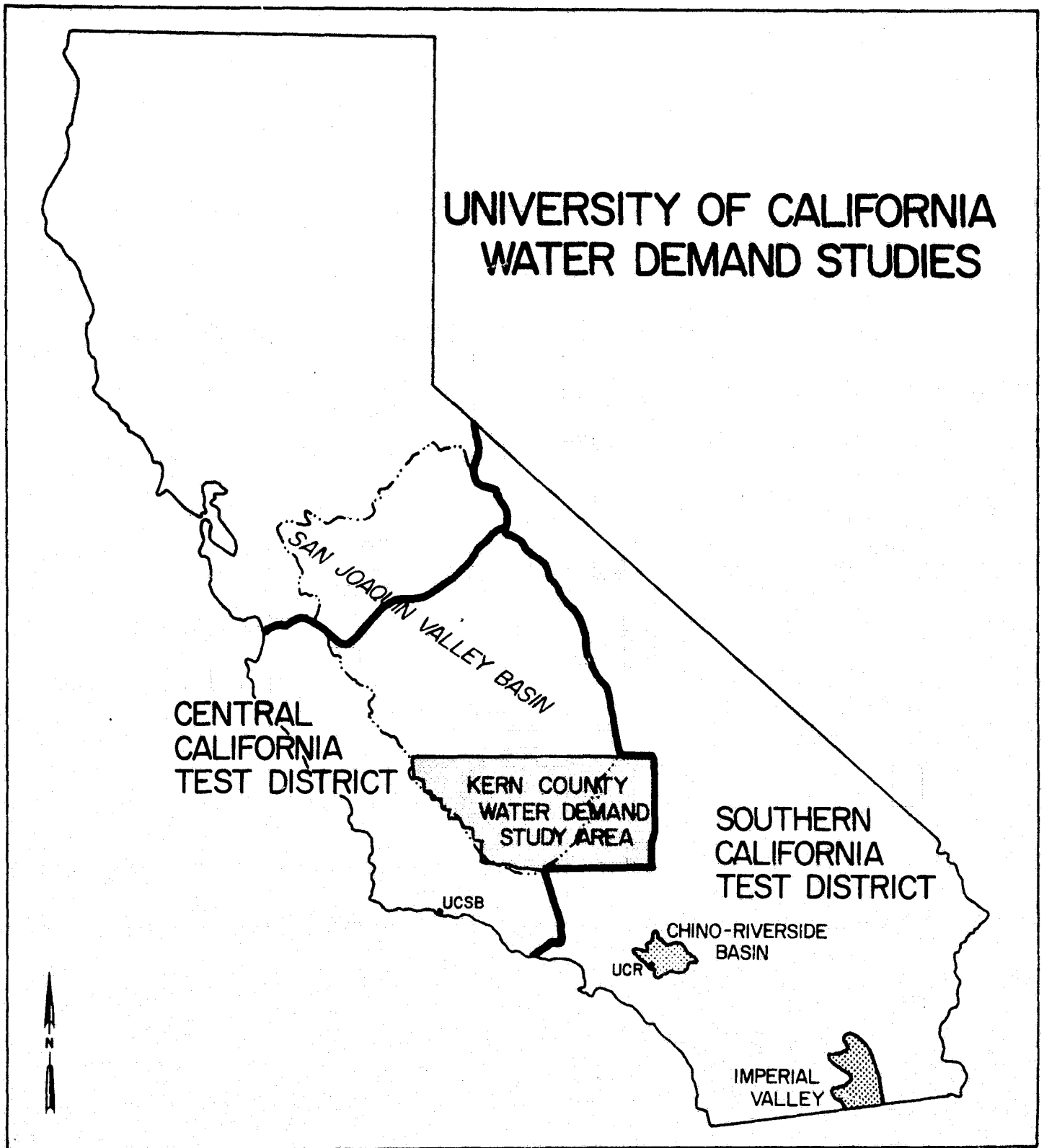


FIGURE 3-1. Central and Southern California Regional Test Districts, and the areas of more specific focus of Water Demand Studies. Kern County, San Joaquin Valley Basin, the Chico-Riverside Basin, and the Imperial Valley.

Work Item	Investigators	Present Funding Year												Next Funding Year											
		75						76						77											
		M	J	J	A	S	O	N	D	J	F	M	A	M	J	A	S	O	N	D	J	F	M	A	
1. Determine critical parameters in water demand models	Riverside (1) Santa Barbara (2) Burgy (1 & 2)	Technically Completed																							
2. Analyze economic impact resulting from changes in water demand information	Public Policy (1&2) Riverside (1) Santa Barbara (2) Churchman (1 & 2) Economist (1 & 2) Lawyer (1 & 2)																								
3. Compute economic effects of <u>changes</u> in estimation of critical parameters	Riverside (1) Santa Barbara (2) Economist (1 & 2) Churchman (1 & 2)																								
4. Evaluate and test remote sensing techniques	Riverside (1) Santa Barbara (2) RSRP (2)																								
5. Determine costs of information-gathering using conventional methods	Riverside (1) Santa Barbara (2)																								
6. Compare remote sensing techniques with conventional ones. Draw conclusions regarding cost-effectiveness	Riverside (1) Santa Barbara (2) RSRP (2) Economist (1 & 2)																								
7. Estimate potential impact of using remote sensing techniques in water demand problems	Riverside (1) Santa Barbara (2) RSRP (2) Economist (1 & 2) Churchman (1 & 2) Burgy (1 & 2)																								

FIGURE 3-2. Chronological Plan for the Assessment of Water Demand by Means of Remote Sensing.
(1) Indicates primary responsibility; (2) Indicates secondary responsibility.

agencies that have a direct and major interest in, and responsibility for, the coordination and planning for water supply, distribution, and allocation. In the GRSU's intensive test region, which is predominantly agricultural, these agencies are (1) Kern County Water Agency (KCWA), and (2) California Department of Water Resources (DWR). These agencies, and particularly KCWA, have continued to play an important and interactive role in our research activities. They have done so by detailing their current water resource activities, suggesting potential remote sensing applications, providing "ground truth" data, and evaluating the potential utility of our methodologies to meet their present and projected data requirements.

In addition to these two major agencies other agencies and organizations concerned with water-related parameters, or having an expertise in crops, soils, hydrology modeling, etc., have also been contacted on an "as needed" basis. These contacts were made primarily to aid in the interpretation and definition of environmental parameters important in terms of hydrologic modeling. Notable among these contacts have been:

- | | |
|---|---|
| 1. University of California
Agricultural Extension
Service at Bakersfield | 6. Kern County Water
Association (at their
request a slide discussion
of GRSU activities in
Kern County was presented
to their Board of Directors) |
| 2. Lost Hills Water
District | |
| 3. Semitropic Water
District | 7. United States Department
of Agriculture's Soil
Conservation Service |
| 4. Wheeler Ridge-Maricopa
Water District | 8. Kern County Agricultural
Commission |
| 5. United States Salinity
Laboratory at Riverside | 9. Tempo Center for Advanced
Studies |

3.03 KCWA HYDROLOGIC MODEL

The computer model of Kern County ground water basin is not a demand model per se in that its major purpose is the total simulation of water storage and movement throughout the ground water basin. The model might therefore, be more appropriately referred to as a "water flow" model. As Kern County is basically a "water demanding"

¹ Tempo received the original contract for the development of the KCWA ground water basin model and continues to be responsible for its operation.

environment (i.e., its arid climate and widespread agriculture require extensive water importations), we have been engaged in a detailed examination of a number of model inputs for possible remote sensing applications for the determination of water demand.

Based upon an analysis of the model, listings of all external quantities that serve as inputs to the model were compiled and analyzed with the aid of KCWA and Tempo personnel. The following steps were involved in the analysis:

1. Data inputs were precisely defined
2. Related inputs were grouped and categorized
3. Present sources of inputs were identified
4. Preliminary determinations were made as to which inputs might be generated more efficiently using remote sensing techniques

Although reported on previously, it is reasonable at this point to recount the basic assumptions associated with the KCWA model and our analysis of the potential role of remote sensing for providing model inputs. Construction of the KCWA model is based upon the following assumptions: 1) That a real-world water basin consists of interbedded layers of sands, clay, silt and gravels which are saturated to some level with water and upon which a variety of land uses are superimposed; and, 2) That the mathematical modeling of such a complex, heterogeneous mass requires that the total complex be subdivided into more workable units of smaller size and greater homogeneity, for each of which valid generalizations can be made.

Within the context of the model the subdivisions that have been made and the assumptions related to them include: (1) subdivision of the surface areas of Kern County into 251 polygons or nodal areas (see Figure 3-3), most of which represent one quarter of a township or approximately 15 square kilometers; (2) the designation of a center point in each polygon which is termed its "node" (all events or circumstances occurring in the area corresponding to a given polygon are assumed to occur at the node); and (3) the movement of water from one polygon to another is assumed to occur along the lines of "flow paths" connecting the nodes. The inset in Figure 3-3 illustrates how the system operates and depicts how the area of Kern County has been subdivided. It is on the basis of these subdivisions that data are collected as input to the model. The final model also takes into account complications resulting from the existence of multilayered aquifers, subsidence, perched water tables and other water related phenomena.

TABLE 3-1

KERN COUNTY WATER AGENCY: CRITICAL HYDROLOGY MODEL INPUTS AMENABLE TO
REMOTE SENSING TECHNIQUES

<u>EXTERNAL QUANTITIES</u>	<u>DEFINITION</u>	<u>SOURCE(S)</u>	<u>REMOTE SENSING CAPABILITIES (IDENTIFY-MEASURE)</u>
<u>Agriculture Useage</u>			
gross irrigated acres	¹ total amount of irrigated acreage	periodic air surveys modified in districts	irrigated croplands
unit agricultural consumptive use	acre-feet per acre water- requirement by <u>individual crops</u> for evapotranspiration	Department of Water Re- sources, experimentation with individual crops	crop identification
<u>Surface & Groundwater Movement</u>			
volume of moisture deficient soil	volume of unsaturated soil	calculated from field work (soil surveys)	soil moisture
% to perched water table	% of node overlying perched water table x nodal deep percolation	field investigations	perched water table areas
<u>External Quantity not yet Incorporated into Model</u>			
soil salinity	salinity of soil as measured by electrical conductivity	field investigation	salinity damage assessment soil salinity prediction

KERN COUNTY: NODAL POLYGON NETWORK

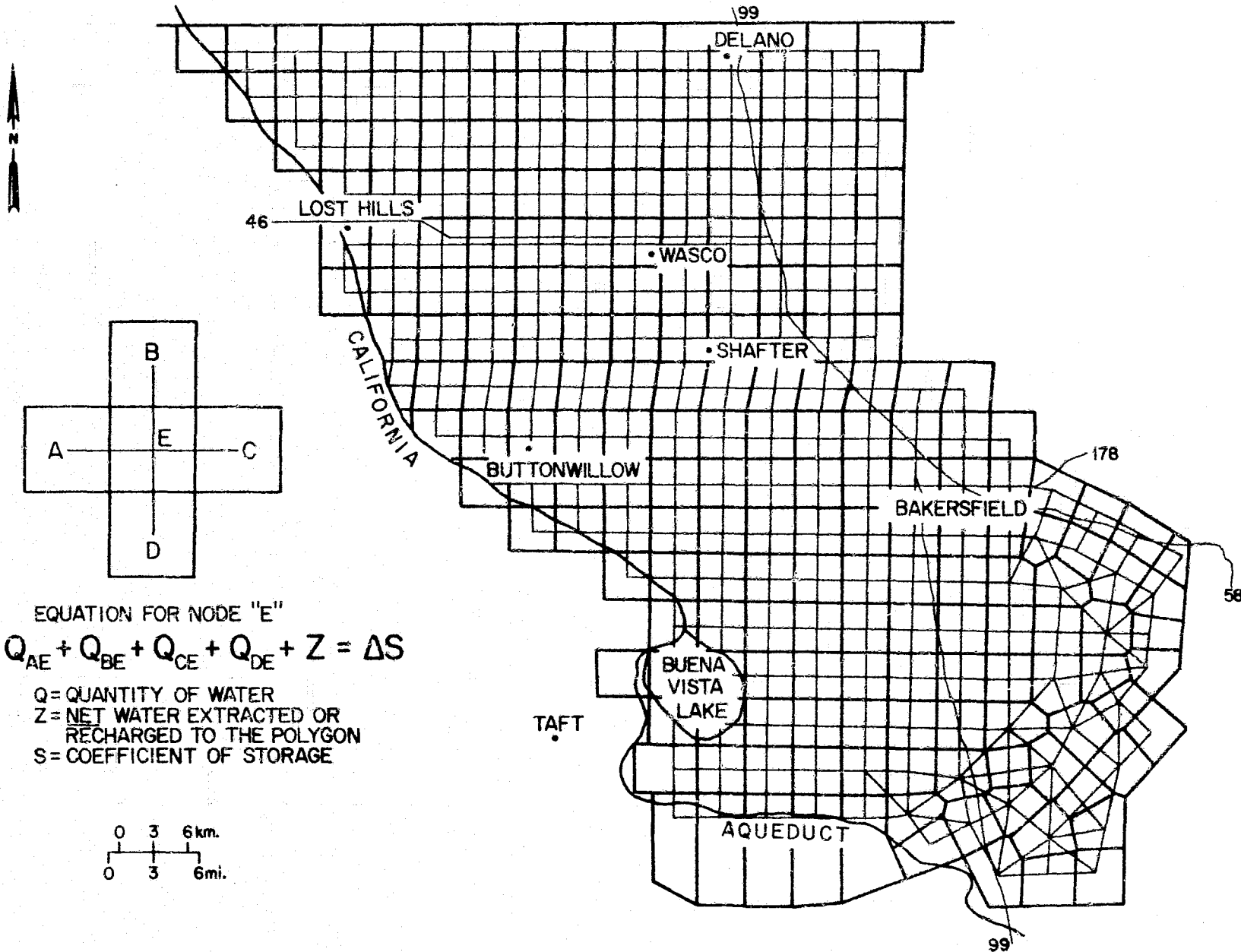


FIGURE 3-3. Kern County Nodal Polygon Network Used to Guide Remote Sensing Studies.

It is important to note (and recognize the importance of the fact) that data are collected and inputted to the model on a nodal basis. As the model is spatially oriented, its effective operation requires that input data maintain proper spatial dimensions and not be aggregated beyond the nodal level. As will be discussed later, this requirement effectively eliminates most sampling procedures for data collection.

In addition to water flow studies, the KCWA hydrologic model has been adapted to delineate zones of equal benefits resulting from KCWA activities. This information is being developed to provide taxation schedules in an attempt to insure that those who benefit from water management policies will pay accordingly. The zones of equal benefit taxation schedules are based upon the following principles:

- * Not all farmers in the region managed by the KCWA are involved in or pay for KCWA activities. These activities include the importation of water, the transfer of water from one water district to another, and the recharging of ground water.
- * By raising the ground water level, these activities benefit non-participants as well as participants.
- * Accordingly, the fairest taxation schedule should incorporate these benefits and be applied to non-participants as well as participants.

As this type of taxation is new it is easy to appreciate that KCWA is hesitant to apply it until it has confidence that the model will withstand any legal challenge to its validity. This application once again stresses the importance of accurate and timely model input data.

Specific determinations as to the benefits that accrue by using remote sensing techniques are difficult to make principally because the model is still in an advanced developmental state. Therefore a fixed set of input data, with specific associated costs for all parameters, is not as yet available. However, it is hoped that in the near future it will become possible to operate the model in two modes, one with strictly conventionally gathered data and the other augmented by remote sensing data. This should allow some estimates to be made as to the sensitivity of the model to various accuracies of remotely sensed data and thus create the foundation of work items 2 and 3, i.e., the analysis of economic impact resulting from changes in the estimation of critical parameters.

Although research on these two work items is just beginning to reach a productive stage the magnitude of potential benefits is

readily apparent. There are currently about 900,000 acres under irrigation in Kern County out of 1,600,000 potentially irrigable acres. The countywide crop value for a section of land (640 acres) is approximately \$500,000 (\$800 crop value/acre x 640 acres/section).² Therefore, in principle, for each 1% of increased efficiency in the application of irrigation waters that results from the use of the hydrologic model, approximately 12.5 additional sections can be brought into production. An addition of this magnitude would represent a crop value of approximately \$6,250,000 dollars.

At the present time, Kern County is overdrafting its ground water basin. Even with the maximum supplies of imported water contracted for in 1990 (the demand for which will be realized in 1980) Kern County will be overdrafting its basin if irrigated agricultural lands are expanded beyond their present areal extent. The situation is critical and the potential benefits which may occur as a result of increased efficiencies derived through the utilization of remote sensing techniques can be significant.

Finally, another extension of the model proposed by KCWA which is currently under investigation involves the incorporation of water quality variables into the present quantity formulations. A major input to water quality determinations will be soil salinity, a topic that is currently being extensively investigated by the GRSU.

The following sections discuss in detail various remote sensing techniques for providing input data to the KCWA model, including both statistical analyses of the value of such data and cost/benefit analyses of these techniques versus present conventional techniques.

3.10 CROPLANDS MAPPING³

3.11 Introduction

The most dynamic element of water movement into and through the Kern County ground water basin occurs as a result of the application of irrigation water on the agriculture lands. In comparison to an

² This is an estimate of the 1974 crop value per acre based on a projection from the 1973 crop value per acre rate of \$720.

³ The term "croplands" as used here is synonymous with "irrigated acreage" as used within the model region of Kern County where it is estimated that 99% of the croplands are actually irrigated (Michael Rector, KCWA Geologist, personal communication).

average Southern San Joaquin Valley precipitation rate of 3 to 5 inches per year, the average irrigation rate is 3.8 acre-feet per year or approximately 32 inches. Irrigation water may be pumped from the ground water basin itself or imported from other regions of the state. Presently, approximately 1,150,000 acre-feet of water is imported yearly while future contractual agreements call for 1,650,000 acre-feet by 1990.

An estimate of the "modelwide" water flow resulting from irrigation activities can be generated from knowledge of the total irrigated acreage and the average application rate. By subtracting the known amount of imported water, an estimate can also be obtained of the county's ground water pumpage. If the KCWA model operated only at a general modelwide scale, effective use could be made of multi-stage sampling techniques combining ground sampling and remote sensing to estimate total irrigated acreage. However, the model does not operate at such a general level and except for providing a method for monitoring general trends such information is of little value. In fact, it is a model requirement that the spatial dimension of cropland data be retained at least to the nodal level of aggregation, i.e., sampling has to be intensive enough to assure high spatial accuracies. Many sampling techniques are impractical under the restrictions imposed by the KCWA model, while mapping approaches such as those explored by the GRSU, have been found both accurate and cost-effective.

3.12 Goal

The amount of irrigation water applied to croplands within Kern County is an important input into the KCWA model. GRSU has been involved in research to utilize remote sensing techniques to generate cropland (irrigation/non-irrigation) maps of the model region. The goal of our research continues to be the refinement and documentation of remote sensing techniques applicable to generating cropland information in a cost-effective manner. Although it is anticipated that in the near future, this cropland data will become a "nested by-product" of our activities with the Berkeley group in automated crop identification, the maintenance of croplands mapping as a separate research entity appears justified as many users do not require information in greater detail or cannot justify the costs of generating specific crop type data. Past mapping has relied heavily upon highlight photography. Its use, however, has been seen as ancillary to and as a logical first step in the development of techniques applicable to the generation of croplands data from LANDSAT type imagery.

3.13 Methodology

Figure 2 in the December, 1974 progress report listed tentative, relative accuracies involved in the acquisition of croplands acreage

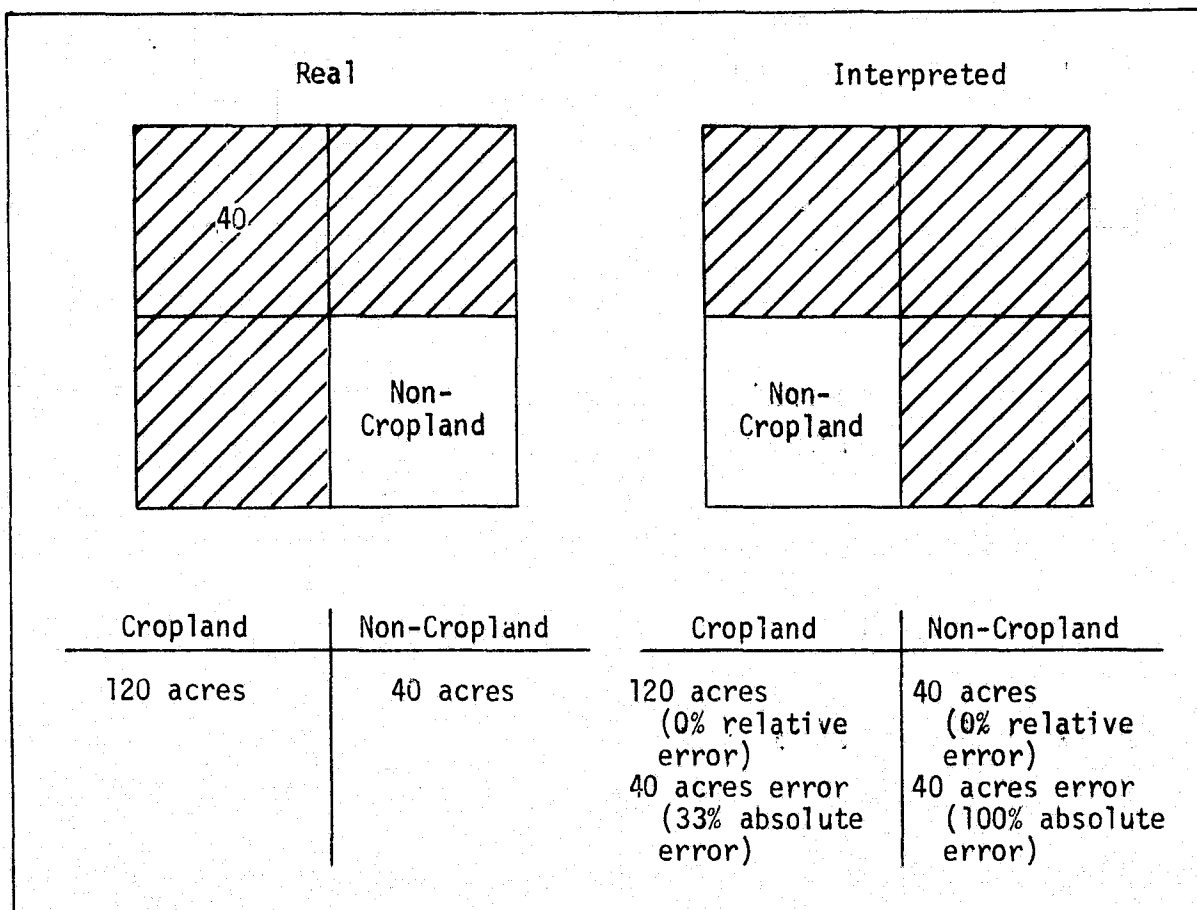


FIGURE 3-4. Example of relative and absolute errors, demonstrating the need for absolute accuracy when spatial information is required.

data utilizing highlight photography, and included one example of the accuracies achieved in croplands mapping from LANDSAT imagery. Recent research has documented both the relative and absolute accuracy as well as the cost-effectiveness of inventorying croplands by:

1. Conventional croplands inventory
2. Highlight 1:125,000 methodology
3. LANDSAT 1:1,000,000 methodology
 - a. Multiband/multidate optical enlargement
 - b. Multiband/multidate color composites, optically enlarged

In working with any remote sensing methodology which generates areal data, and more specifically one associated with a nodal model of the type employed by KCWA, it is important to evaluate both relative and absolute accuracies in order to assess the actual utility of a specific remote sensing inventory methodology. For example, consider Figure 3-4 which depicts the hypothetical ground truthed and interpreted condition of one section of land.

In this hypothetical example the interpretation of cropland can be 100% accurate in the relative sense yet 100% inaccurate in the absolute sense. Although a total of 120 acres were correctly interpreted as being cropland, 40 acres were spatially misinterpreted, giving rise to a 33% absolute error. In addition, 40 acres of non-cropland were completely misinterpreted, representing a 100% absolute error in terms of non-cropland spatial location. In our research it is important for us to ascertain the percent absolute error because of the KCWA hydrologic model requirement of spatially correct data to at least the nodal level. In effect, the non-spatial, relative data might prove sufficient for certain applications, e.g., county-wide water application estimation, while absolute information concerning croplands present must be known on a nodal basis for the detailed hydrologic modeling. Both the relative and absolute accuracies obtained utilizing the various information gathering methodologies listed above will be discussed in detail.

3.14 Results

3.141 Conventional Croplands Inventory

Ground truth information employed in the assessment of the interpretation accuracies associated with this portion of our research were compiled by the Lost Hills (76,691 acres), Semitropic (224,000 acres), and Wheeler Ridge-Maricopa (155,300 acres) Water Storage Districts located in Kern County (see Figure 3-5 for district

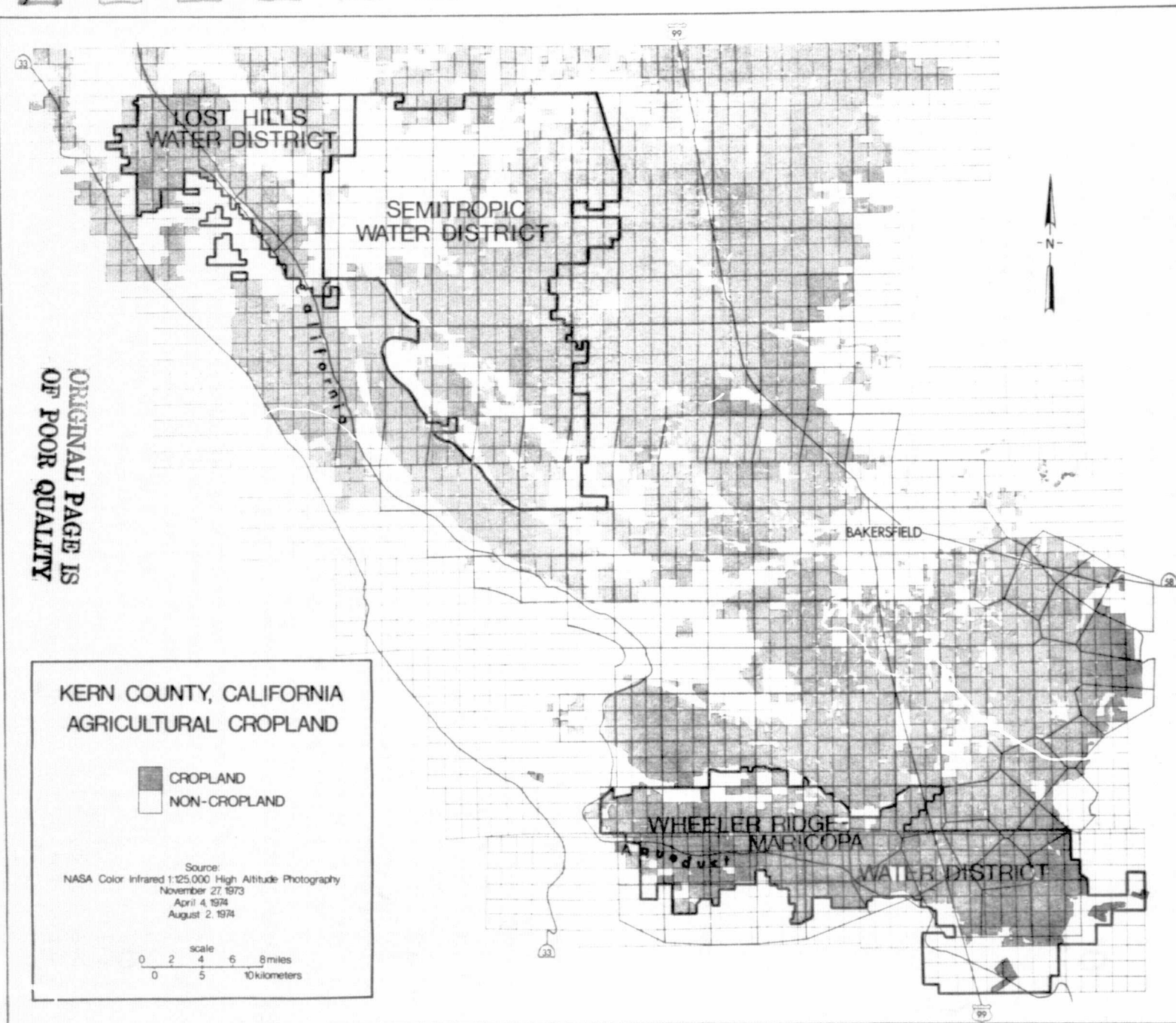


FIGURE 3-5. District boundaries for three Kern County water districts studied for cropland mapping.

boundaries). The districts determined the August, 1974 condition of fields (cropland or non-cropland) by terrestrial examination. These data, although recognized as having their own variance, served as a control against which the remote sensing methodologies were tested for accuracy.

Individual district costs associated with the acquisition of the terrestrial cropland data are summarized in Table 3-2. The total estimated cost for conducting this 456,000 acre inventory for all three districts comes to \$3,000 and requires 6 weeks to implement. At this rate the cost for inventorying each 10,000 acres of cropland is approximately \$66.00.

The California Department of Water Resources (DWR) has estimated that a croplands survey of Kern County could be undertaken for approximately \$5,000. This would require the assessment of over 1,600,000 potentially irrigable acres of land to ascertain whether each acre is currently cropland or non-cropland (in the case of Kern County basically irrigated vs. non-irrigated). Thus, the DWR croplands inventory cost, utilizing oblique color aerial photography (35mm) and some ground truth, is estimated to be \$31.25 per 10,000 acres. Therefore, the cost would be \$1424 for DWR to inventory the 456,000 acres in the three water districts under investigation.

3.142 Croplands Inventory Utilizing Highlight 1:125,000 Color Infrared Photography

To assure a uniform scale in the highlight cropland inventory maps generated for KCWA, mapped data is transferred to an acetate copy of a photogrammetrically controlled 1:125,000 basemap. These maps include all nodal and section boundaries in the valley portion of Kern County. As the 1:125,000 highlight image scale corresponds almost exactly with the 1:125,000 basemap the visual transfer of cropland detail can be accomplished with relative ease and without ancillary equipment. A majority of field boundaries and roads follow section lines. Whenever a variation between photo and map scale exists, such as that introduced by geometric distortions away from the nadir, the photograph (or map) can be adjusted on a section by section basis. Normally, realignment is necessary only every few townships if the major portion of the area under investigation is in the central portion of the photography.

As would be expected the primary object recognition feature for identifying croplands is the magenta signature expressed for healthy vegetation; however, hue may vary from dark to light in agricultural production areas depending upon the stage of the phenological cycle that a specific crop is in. The optimum date for utilizing high-flight photography for croplands inventories in Kern County has now been documented as being August, which is the height of the growing season for cotton (which comprises approximately 30% of the agricultural

TABLE 3-2

Estimated Costs for Terrestrial Cropland Survey

Mapping Agency	Cost for Inventorying the Entire District	Total Acres in District	Total Cropland Acres Inventoried	Time Required to Inventory Each District
		Inventory Cost for Each 10,000 acres		
Lost Hills Water Storage District (Terrestrial)	\$500	76,691 acres (\$65)	50,504 acres (\$99)	40 hrs.
Semitropic Water Storage District (Terrestrial)	\$1500	224,000 (\$67)	124,000 (\$120)	120 hrs.
Wheeler Ridge-Maricopa Water Storage District (Terrestrial)	\$1000	155,300 (\$64)	113,807 (\$87)	80 hrs.
TOTAL	\$3000	455,991 (\$66)	288,701 (\$104)	240 hrs.
Department of Water Resource (DWR) Estimate for Inventory- ing the 3 Districts (Low Flight and Terrestrial)	\$1424	455,991 (\$31.25)	288,701 (\$49.32)	230 hrs.

acreage of our study area). A minor problem which exists with respect to the application of single date highflight photography has been that abandoned fields are often difficult to differentiate from fallow fields. In addition, uniform grasslands completely enclosed by croplands are at times misinterpreted as irrigated crops.

The applicability of this highflight technique to other irrigated agricultural regions will be dependent upon the phenological cycle of the major crops, cloud cover, and how faithfully croplands follow systematically surveyed land subdivisions. For metes-and-bounds cadastral systems, visual scale matching time would be increased significantly owing to the non-symmetric geometry of field shapes. In Kern County, however, with a uniform systematic cadaster, the highflight technique is quite successful. For example, three dates of highflight photography have been used to compile croplands data with this procedure: November 27, 1973 (Flight #73-194), April 4, 1974 (Flight #74-049), and August 2, 1974 (Flight #74-133). Data presented in Figure 3-5 represents a synthesis of the information concerning the total irrigated agricultural lands in Kern County compiled from highflight imagery taken on the dates listed above.

Table 3-3 illustrates that for the 456,000 acres in the three Water Districts studied, the highflight croplands inventory had a mean relative and absolute error of 1.47% and 2.82% respectively. This means by utilizing highflight photography to acquire cropland data on a spatial nodal basis, that out of 288,701 acres classified as being cropland, greater than 97% of these lands were correctly inventoried.

The cost for acquiring croplands data by CIR highflight imagery is cost effective when compared to terrestrial conventional methods. By referring to Table 3-4 it can be seen that for each 10,000 acres inventoried the cost is approximately \$.87 per 10,000 acres. The \$40.00 it cost to acquire remote sensed cropland data for the three districts represents only 1.3% of the \$3000 cost incurred by the water storage districts inventory. Time required for the GRSU to complete this three district analysis is minimal (only 8 hours). Each district requires a maximum of only three 9" X 9" transparencies which are at the same scale as the basemap. Despite the high accuracies and cost effectiveness of inventorying croplands with highflight imagery which we indicate here, it must be kept in mind that this analysis does not take into consideration the cost of aircraft mobilization or image acquisition. If user agencies are interested in implementing a highflight methodology for the inventory of croplands under their jurisdiction, their first priority should be to contact the EROS Data Center at Sioux Falls, South Dakota and acquire a catalog of the U-2 imagery available for their study area. If imagery is available it can then be ordered for a nominal processing price. Croplands inventories can then be initiated for the dates on which imagery is available and updated based on new overflights.

TABLE 3-3

Relative and Absolute Accuracy of Cropland Acreage Estimates as Derived from Highlight Photography, Multidate/Multiband LANDSAT and Color-Combined LANDSAT Imagery

Water District (Total Acres)	Water District Field Check		Highlight 1:125,000		(Band 5 and 7) LANDSAT 1:1,000,000		(Color Composite) LANDSAT 1:1,000,000	
	Cropland acres	Non-Cropland acres	Cropland acres (% relative error) acres (% absolute error)	Non-Cropland acres (% relative error) acres (% absolute error)	Cropland acres (% relative error) acres (% absolute error)	Non-Cropland acres (% relative error) acres (% absolute error)	Cropland acres (% relative error) acres (% absolute error)	Non-Cropland acres (% relative error) acres (% absolute error)
Lost Hills (76,691 acres)	50,504	26,187	50,930 (.84%) 2,360 (4.67%)	2,576 (1.63%) 1,440 (5.5%)	50,134 (.74%) 1,495 (2.96%)	26,557 (1.41%) 227 (.86%)	51,105 (1.19%) 2,000 (3.96%)	25,586 (2.29%) 1,500 (5.72%)
Semitropic (224,000 acres)	124,390	99,610	123,635 (.61%) 1,520 (1.22%)	100,365 (.75%) 4,235 (4.25%)	122,480 (1.54%) 1,620 (1.3%)	101,520 (1.91%) 3,500 (3.51%)	121,480 (2.34%) 2,310 (1.85%)	102,520 (2.92%) 3,827 (3.84%)
Wheeler Ridge- Maricopa (155,300 acres)	113,807	41,493	117,185 (2.96%) 2,945 (2.58%)	38,115 (.91%) 420 (1.01%)	114,385 (.51%) 1,955 (1.71%)	40,915 (1.4%) 650 (1.56%)	115,020 (1.06%) 3,040 (2.57%)	40,280 (2.97%) 740 (1.78%)
Total	288,701	167,290						
		\bar{X} relative error	1.47%	1.09%	.93%	1.57%	1.53%	2.72%
		\bar{X} absolute error	2.82%	3.58%	1.99%	1.97%	2.82%	3.78%

TABLE 3-4

Costs for Highlight Cropland Inventory

GRSU U-2, 1:125,000 Cropland Inventory	Cost for Inventorying the Entire District	Total Acres in District	Total Cropland Acres Inventoried	Time required to Inventory Each District
		Inventory Cost for Each 10,000 acres		
Lost Hills	\$8.75	76,691 (\$1.14)	50,930 (\$1.71)	1.75 hrs. @ \$5.00 =\$8.75 To update croplands using August, 1974 highflight photography
Semitropic	\$17.50	224,000 (\$.78)	123,635 (\$.70)	3.5 hrs. @ \$5.00 =\$17.50 to update
Wheeler Ridge- Maricopa	\$13.75	155,300 (\$.89)	117,185 (\$1.18)	2.75 hrs. @ \$5.00 =\$13.75 to update
TOTAL	\$40.00	455,991 (\$.87)	291,750 (\$1.37)	8 hrs. @ \$5.00 =\$40.00 to update 3 districts

3.143 Croplands Inventory Utilizing LANDSAT 1:1,000,000 Multiband (Bands 5 and 7), Multidate Optical Enlargement Techniques

Several problems encountered with the highlight 1:125,000 technique are solved by using LANDSAT scale imagery, with no loss in accuracy. For example, the problem of acquiring multidate imagery of a specific study area is simplified because LANDSAT type imagery is currently available at 9 day intervals for all the earth's croplands. Atmospheric conditions permitting, user agencies can now acquire sufficient imagery throughout the year to conduct a cost-effective cropland inventory. The synoptic view and greater geographic coverage (109 X 109 nautical miles) per frame is a further benefit as a greater amount of land can be inventoried on a single frame resulting in a smaller expenditure for imagery. Of particular importance is the multiband (4, 5, 6, 7) capability of multispectral scanner data which allows the user to choose those bands best suited to detecting cropland in a particular environmental study area.

Whenever LANDSAT type imagery is used it is usually necessary to enlarge the original imagery through optical or photographic techniques. GRSU has created 8X photographic enlargements (1:125,000) of single band/single date LANDSAT frames and compared these with optically enlarged LANDSAT frames. The basic conclusion is that no difference exists between the two enlargement techniques with respect to interpretation accuracy of croplands data. Therefore, the LANDSAT optical overlay methodology, discussed below, can just as effectively be employed by using photographic enlargements of a LANDSAT frame.

Copies of a 1:125,000 scale basemap of the three districts were produced and distributed to interpreters. By using an optical enlarging instrument (Bausch and Lomb's Zoom-Transfer-Scope) each interpreter was instructed to inventory the croplands of the three districts separately. Each interpreter utilized the same 5 dates, which were previously determined as being optimum in terms of resolution, % cloud cover, and date in the phenological cycle. By utilizing an optical enlarging instrument the interpreter can simultaneously view a single date (single band) of LANDSAT imagery and the 1:125,000 basemap. For each date of imagery a separate analysis of cropland acreage was recorded. A composite map of the 5 single overlays was then generated with the most recent date of imagery being used as the data base and all data discrepancies between this and earlier dates being carefully analyzed. In this manner a composite LANDSAT cropland map was generated by each interpreter for each district and these maps were compared against the ground-truth district maps to assess interpretation accuracy. The results in Table 3-3 represent the mean cropland/non-cropland acreage estimates for interpreters involved in the inventory of each district.

TABLE 3-5

Cost for LANDSAT Multidate, Multiband (5 and 7) Cropland Inventory

GRSU LANDSAT, 1:1,000,000 Multidate, Band 5 & 7 Cropland Inventory	Cost for Inventorying the Entire District	Total Acres in District	Total Cropland Acres Inventoried	Time Required to Inventory Each District
		Inventory Cost for Each 10,000 acres		
Lost Hills	\$14.55	76,691 (\$1.89)	50,134 (\$2.90)	5 bands @ .583 hrs. = 2.91 hrs. 2.91 hrs. @ \$5.00 =\$14.55
Semitropic	\$37.50	224,000 (\$1.67)	122,480 (\$3.06)	5 bands @ 1.5 hrs.= 7.50 hrs. 7.5 hrs. @ \$5.00 = \$37.50
Wheeler Ridge- Maricopa	31.25	155,300 (\$2.01)	114,385 (\$2.73)	5 bands @ 1.25 hrs.=6.25 hrs. 6.25 hrs. @ \$5.00 = \$31.25
TOTAL	\$82.50	455,991 (\$1.81)	288,701 (\$2.85)	15 bands @ 1.1 hrs. = 16.5 hrs. 16.5 hrs. @ \$5.00 = \$82.50

The mean relative error for LANDSAT cropland inventories was found to be less than 1%, while the mean absolute error was less than 2%. This is significant because even though the scale has been decreased and resolution degraded when compared to highflight 1:125,000 imagery, the LANDSAT technique is capable of achieving better relative and absolute accuracies of 99% and 98% respectively. The interpreters involved in this research attribute this to the multirate capacity of LANDSAT to provide good resolution for many dates throughout the growing season. Also, band 5 (.6-.7 μ m) was judged the optimum spectral region for the analysis as it imaged planted agricultural fields as being dark against a lighter background, thus facilitating both the process of interpretation and transfer of detail.

By analyzing Table 3-5 it can be seen that the costs associated with inventorying the three districts via LANDSAT overlays is approximately \$82.50 or \$1.81 per 10,000 acres. The relatively higher cost per district for this type of inventory compared to highflight is due to the longer time required to compile the 15 separate overlay maps, with the mean time per date (single band) for creating an overlay being 1 hour. Certainly more dates (single band) could be interpreted to develop the composites but to acquire a 1% increase in accuracy would require a 50% increase in interpretation time and costs. The GRSU feels that a 5 band LANDSAT composite costing only \$1.81 per 10,000 acres at 98% absolute accuracy is sufficiently cost-effective for most croplands inventory user needs.

3.144 Croplands Inventory Utilizing Multirate, Multiband Color-Combined LANDSAT Imagery

After some initial experimentation it was found that when band 5 and band 7 of a single or multiple date of LANDSAT imagery are color combined (band 5 filtered with a green filter and band 7 with a red filter) that a color combination takes place which facilitates the interpretation of croplands. In many situations band 5 and band 7 image the reciprocal signature of one another with respect to agriculture or other forms of vegetation. Agricultural cropland usually registers as dense (dark) on band 5 and transparent (approaching clear) on band 7. The following example will serve to explain the significance of this band 5 and 7 dichotomy as it relates to color combining. When color film is exposed through a green filter with band 5 back-lit by white light, the opacity of an agricultural field will allow very little green light to expose the negative. Conversely, when the same field in band 7 is registered in the exact location, back lighted, and exposed through a red filter, the transparency (less dense) of the field will allow the transmission of red light. This will expose the emulsion with red light and create a dark red image when the latent image is chemically processed. When the signature of a field is mid-gray in density on either band 5 or 7

then various hues of green-yellow-red are created. By carefully training with the known color combined signature of bare soil, fallow and cropped fields it is possible to identify these conditions with considerable accuracy. The image interpreters were also given a 3-color composite and trained to interpret signatures for bare soil, fallow and cropped lands.

Separate overlays were made for each color composite with a final cropland map for each district being a synthesis of the three maps. By examining Table 3-3 it is apparent that the color-composite cropland relative and absolute accuracies compare favorably with the highlight methodology while the non-cropland accuracies are the poorest of the methods tested. In effect, the 3.78% absolute error for non-croplands means that the interpreter assessed several fields as non-cropland while the district field crews identified them as cropland. GRSU believes that the reason for this misinterpretation may be due to two factors. First, the dates chosen do not provide the optimum color combinations for inventorying croplands in this region. This may be the case even though the particular dates employed were chosen, initially, because of their high accuracy when used in the LANDSAT black-and-white analysis. Additional research may identify certain dates which when color composited yield a more optimum enhancement. Secondly, although interpreters were trained as to what each specific color should represent, there was some ambiguity at certain times as to what color the interpreter was actually viewing. This we believe led to errors at the cropland/natural vegetation interface where most of the interpretation errors associated with this test seemed to be concentrated (specifically, near the saline and perched water drainage areas). In several instances it was found that for the 2-color composites a greenish-red hue could systematically be misinterpreted by several interpreters when the value (tone) is very light.

In terms of cost, the color composite methodology lies midway between the highlight and LANDSAT black-and-white inventories. Table 3-6 illustrates that the color composite inventory was \$1.48 per 10,000 acres or \$67.50 for the entire 455,991 acres of the three combined districts.

3.15 Summary

In terms of overall mean relative and absolute accuracy the LANDSAT multitime, multiband black-and-white analysis yields the best results, 98% accuracy. The highlight method is a serious alternative which can be very accurate if coverage is available for a specific study area. The LANDSAT color combined estimate fell somewhat short of GRSU's expectations in terms of absolute accuracy which may in reality be to some extent a function of the dates selected for this investigation. Nevertheless, when all three techniques are compared together, at no point do the mean relative

TABLE 3-6

Costs for Color Composite LANDSAT (Multidate, Multiband) Cropland Inventory

GRSU Color Composite LANDSAT 1:1,000,000 Multidate, Multiband, color composite cropland inventory	Cost for Inventorying the Entire District	Total Acres in District	Total Cropland Acres Inventoried	Time Required to Inventory Each District
		Inventory Cost for Each 10,000 acres		
Lost Hills	\$11.25	76,691 (\$1.46)	51,105 (\$2.02)	3 color composite overlays @ .75 hr. = 2.25 hrs. 2.25 hrs @ \$5.00 =\$11.25
Semitropic	\$30.00	224,000 (\$1.34)	121,480 (\$2.46)	3 color composite overlays @ 2 hr. = 6 hrs. 6 hrs. @ \$5.00 =\$30.00
Wheeler Ridge- Maricopa	\$26.25	155,300 (\$1.69)	115,020 (\$2.28)	3 color composite overlays @ 1.75 hr. = 5.25 hrs. 5.25 hrs. @ \$5.00 =\$26.25
TOTAL	\$67.50	455,991 (\$1.48)	287,605 (\$2.35)	13.5 hrs. @ \$5.00 = \$67.50

TABLE 3-7

The Cost-Effectiveness of Terrestrial Versus Remote Sensing Techniques for Cropland Inventories

Cropland Mapping Agency (Technique)	Cost for Inventorying all 3 Districts	Total Acres in All 3 Districts	Total Cropland Acres Inventoried	Time Required to Inventory All 3 Districts
		Inventory Cost for Each 10,000 acres		
Lost Hills, Semitropic Wheeler Ridge Water Districts (Terrestrial)	\$3,000	455,991 (\$66)	288,701 (\$104)	240 hrs. @ \$12.50 hr.
Department of Water Resources (DWR) (Lowflight & Terrestrial)	\$1424	455,991 (\$31.25)	288,701 (\$49.32)	230 hrs. @ \$6.20 hr.
GRSU - 3 Districts U-2 1:125,000 (Highflight Inventory)	\$40*	455,991 (\$.87)	288,701 (\$1.37)	8 hrs. @ \$5.00 hr to compile basemap
GRSU - 3 Districts LANDSAT 1:1,000,000 (Multidate, Band 5 or 7)	\$82.50	455,991 (\$1.81)	288,701 (\$2.85)	16.5 hrs. @ \$5.00 hr. +
GRSU - 3 Districts Color Composite LANDSAT 1:1,000,000 (Multidate, Multiband Color Composite Inventory)	\$67.50	455,991 (\$1.48)	288,701 (\$2.35)	13.5 hrs. @ \$5.00 hr. °

* Does not include aircraft mobilization or the cost of photography

+ Each district was inventoried by making 5 single date, single band (5 or 7) overlays and then compositing these to form the cropland map. The dates examined required a mean interpretation time of 1 hour. Therefore, the three districts required a total of 15 separate LANDSAT maps @ 1 hour each totaling 16.5 hours.

° Each district was inventoried by making 3 cropland overlays from 3 different LANDSAT color composites. The color composites were produced by registering and photographically combining multidate and multiband images into a 2 or 3-color composite. The district map represented a composite of these 3 interpreted color composites. Therefore, the 3 districts required a total of 9 separate LANDSAT maps @ 1.5 hrs. each totaling 13.5 hours.

or absolute accuracies fall below 96% (Table 3-3).

The remote sensing croplands inventories documented are cost-effective (Table 3-7). Compared to the \$31-66 cost per 10,000 acres for the DWR and Water District cropland inventories, the high-flight and LANDSAT inventories required only 2-4% of this amount; \$.87-1.81 per 10,000 acres. The mean time for the DWR and Water District inventories was 235 hours while the remote sensing inventories required only 12 hours. This represents a 95% reduction in time when croplands are inventoried using highflight or LANDSAT techniques.

3.20 CROP IDENTIFICATION

3.21 Introduction

The identification and mapping of croplands in Kern County allow the preparation of a first-order approximation of water demand. However, the specific irrigation requirements of various crop types introduce substantial error in the individual nodal demand values if a county-wide average application rate is assumed to be representative of the average application rate within each node. By examining Table 3-8 one can see that whenever a concentration of one of the county's three major crops occurs and the countywide application rate of 3.38 acre-feet/gross acre assumed, potential errors approaching 150% overestimation and 15% underestimation can result. Even larger errors are possible if concentrations of some other crops, e.g. rice, were to occur.

KCWA has eliminated a large portion of this potential error by utilizing a 1969 DWR crop group survey¹ and various updates made available by individual water districts. The use of such dated information, however, introduces errors whenever the yearly crop type composition within a node varies. This is especially true of the

TABLE 3-8
Yearly Crop Irrigation Requirements for Kern County
(Agricultural Crop Report, 1973, County of Kern)

<u>Crop</u>	<u>Requirement</u>	<u>Percent Total County Irrigated Acreage</u>
Barley	1.4 acre-feet	7%
Cotton	2.6 acre-feet	32%
Alfalfa	4.0 acre-feet	15%

¹ A "crop group" is an aggregated classification scheme that generalizes specific crop types into useful groups, e.g., row crops, orchards, field crops, etc.

newer croplands within the county, where crop experimentation is being conducted to determine which crops are well adapted to the region. KCWA personnel have specifically stated that the generation of accurate and timely crop type maps should be a major goal of GRSU water demand research.

Although KCWA cannot currently fund such surveys, crop type information is still considered an important input to the ground¹-basin model. The DWR estimated cost of \$34,000 for these surveys makes it highly infeasible that the KCWA will be able to undertake conventional crop surveys as an individual effort. With many agencies (including among others those previously mentioned in the croplands mapping section) constituting potential users of crop identification information, KCWA personnel envision a cooperative effort in the near future. Preliminary discussions have already begun among some of these potential user agencies to define their individual information requirements. It will be important to consider the multiple uses of this type of information in our cost-benefit analysis of remote sensing techniques.

3.22 Goal

The major aim of this portion of our research is to develop a procedure capable of cost-effectively implementing remote sensing techniques to generate crop type data, on a nodal basis, as input to the KCWA model. From the beginning of this work it was, and still is, believed that the temporal nature of this task would require multi-date imagery. It is this type of task for which LANDSAT imagery is well suited.

The present cost associated with conventional county-wide crop mapping (e.g., DWR's estimate) makes such an endeavor prohibitive on a yearly basis, even though there is an acknowledged need for such information by many potential users. Efforts to initiate a multi-agency cooperative yearly crop mapping program, based upon conventional techniques and at their known costs, is demonstrative of the perceived need for this type of information. Accordingly, a secondary goal of our research is to document the informational requirements of these additional user agencies and where appropriate, incorporate them into a crop identification methodology based upon remote sensing techniques.

3.23 Methodology

The validity of using multi-spectral and temporal analysis techniques for crop identification from LANDSAT-type imagery has

¹ This estimate is for a field survey supported by extensive low altitude 35mm oblique aerial photography.

been well documented. Multispectral analysis is based upon the premise that tonal differences typically exist between objects (in this case agricultural fields) within some portion of the electromagnetic spectrum. Optimum use of these differences as a means of identifying the objects depends upon the exploitation of many variables, of which the band width and spectral sensitivity of the remote sensing system are typically the most controllable.

Temporal analysis, as it pertains to crop identification, commonly involves the use of a "crop calendar" such as that included in our last Annual Report for the major crops in Kern County. With knowledge as to the types of crops present in a region and their respective planting-growing-harvesting cycles, probabilistic statements can be generated as to the likelihood of a field appearing in a given condition on any certain date, or set of dates, and belonging to a given crop class. The extension of these analysis techniques into an operational procedure for a region as large as that encompassed by the KCWA model (approximately 900,000 acres), however, is a difficult task. This is especially true in this particular region where a large variety of crops are grown and the informational requirements of the KCWA hydrologic model demand data that is accurate at the nodal level. The procedures developed for the task of crop identification may be subdivided into three sections: multiple image correlation, data extraction, and classification. The need for multiple image correlation results from the need to register in some manner the same point, or in our case the same field, on each of the images used in the multiband and/or multirate analyses. Most manual techniques for field identification typically involve the enlargement of 1:1,000,000 LANDSAT images to a more useable scale of approximately 1:100,000. However, any photographic enlarging process will entail a decrease in resolution and a loss of information while optical projection enlargement limits the methods available for data extraction.

To alleviate this situation the GRSU has investigated techniques for operating at the original image scale of 1:1,000,000 utilizing both optical as well as video magnification. The task of identifying individual fields has been accomplished by producing field boundary maps for each node or group of nodes and then reducing each map to the exact scale of LANDSAT imagery. The inclusion of prominent features in the map, such as canals and highways, makes alignment of the reduced overlay upon the imagery a relatively simple task. The most important requirement for this approach is that precision photographic facilities be available to insure correctly scaled reductions. Figure 3-6 is an example of a reduced overlay placed upon a LANDSAT image and the combination photographically enlarged for inclusion in this report. Such field boundary overlays provide a method for multiple image correlation, with data then extracted on a per field basis from successive images.

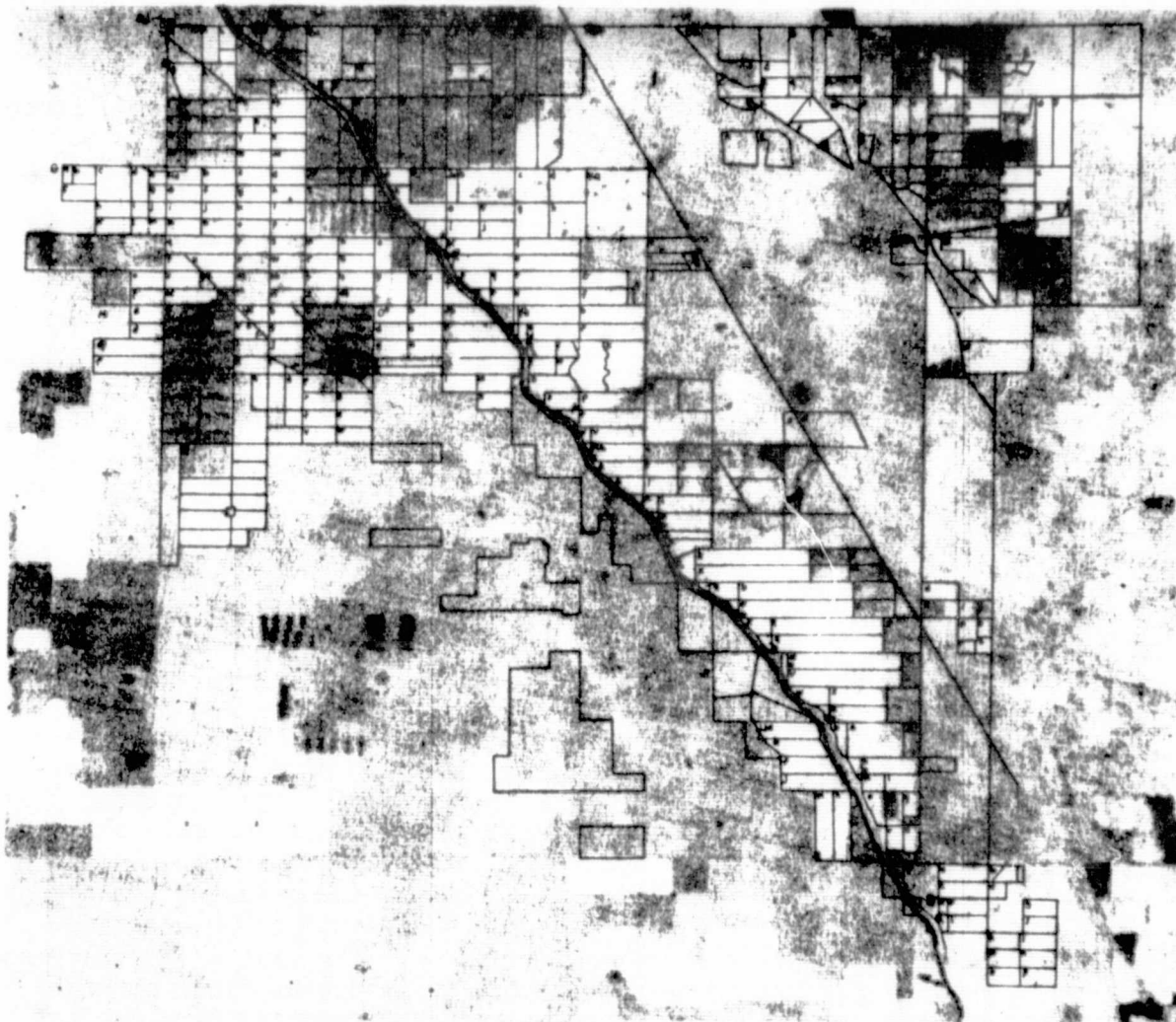


FIGURE 3-6. Field boundary overlay placed upon LANDSAT image and the combination photographically enlarged for inspection.

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This technique was reported in detail in our May, 1974 Grant report. Recent improvements to this procedure include the use of high contrast prints instead of continuous tone transparencies for the LANDSAT enlargements and a more operable mapping scale of 1:62,500. At this scale the LANDSAT enlargement can no longer be visually compared in a rapid manner to 1:125,000 scale photography, as required by our procedure. An optical comparator is now used to more effectively transfer detailed field boundary information from the high altitude photography to an acetate overlay placed upon the LANDSAT enlargements.

The utility of a field boundary overlay reduced to LANDSAT scale would decrease if field boundaries were to markedly change. We have examined three representative agricultural regions in Kern County, each approximately 23,000 acres, to determine the magnitude and characteristics of field boundary changes. The results of this examination suggest updates every two to three years should suffice if interim maps indicating only the changed boundaries are used as an additional guide to data extraction. More conclusive results will be available in our next report.

Data extraction is now being manually accomplished utilizing the Geography Department's video image analyzer. The use of the video image analyzer, capable of point optical density measurements, has facilitated the extraction of tonal density values on a per field basis. The system is being used in conjunction with the field boundary overlays to extract "training" data from each set of imagery for which GRSU has ground truth information. A systematic survey of over 700 fields on the west side of the San Joaquin Valley has been in progress over the last 4 years in anticipation of the need for adequate, accurate ground truthed crop information.

The video image analyzer is currently being integrated into the UCSB Computer System Laboratory's (CSL) Interactive Signal Processing System, thereby greatly expanding the GRSU's image processing capabilities. The digital image processing system will allow various automated and semi-automated techniques for data extraction as well as analysis to be explored. This system will also provide the basis for a remote terminal with access to the RSRP CALSCAN pattern recognition programs. Both will be discussed later in a separate section on image processing (section 3.7)

The final stage of crop identification involves the analysis of field spectral signatures to determine whether individual crop types exhibit adequate uniqueness (and uniformity) to allow accurate classification. Sorting and plotting programs have been developed by the GRSU and provide rapid and economical visual analysis of field data. Another program developed by our group determines optimum dates for pairwise crop discrimination by analyzing the amount and

degree of spectral overlap between pairs of crop types. These programs allow an effective graphic presentation of the data while a discriminant analysis program, made available to the GRSU by our colleagues on the Berkeley Campus, provides a thorough statistical analysis and automatic classification of the data. The preliminary results of such a classification, using data previously obtained using a manual optical microdensitometer, are considered encouraging but too incomplete to be included in this report. More conclusive results, including those obtained utilizing the video system, will be detailed in future reports.

3.24 Crop Identification Application: Cotton

One potential user of specific crop identification information is the Plant Protection Service of the Department of Agriculture in their program to control pink bollworms. Title 3 of the California Administrative Code, Section 3595, names Kern County as a member of Host-Free District 4, which requires that from December 15 through March 15 no cotton plants or parts thereof may be present "in a state or condition capable of sustaining or continuing pink bollworms in any stage." The U.S.D.A. currently generates each year a June 15 cotton distribution map by field investigation (approximate cost \$8,000) for use in its summer moth trapping program. Any expansion of the current pink bollworm population will most likely also result in the necessity of a winter plowdown monitoring program. The GRSU intends to fully document the feasibility of remote sensing techniques for generating the information required for these programs. The first stage of this effort entails an analysis of the specific informational requirements of this application. These requirements are: 1) The knowledge of the cotton crop calendar for Kern County, including planting (March 15-April 20), growing (April 20-September 15), harvesting (September 15-December 15), and plowdown (December 15-March 15); 2) The spectral reflectance signatures of cotton on LANDSAT imagery during the appropriate period of cotton's phenological cycle; 3) The probability of having $\leq 20\%$ cloud cover for the Kern County region. The general procedure for developing these probabilities is discussed in the cloud cover analysis portion of this chapter (section 3.4). The impact of cloud cover on cotton inventorying and plowdown monitoring, as well as croplands mapping, is demonstrated in detail.

This user agency application is one of several potential uses of crop identification data that remain to be investigated in order to provide a thorough cost-benefit analysis of our remote sensing techniques. Complete results from the 1975 growing season will be included in our next report.

3.30 WATER DEMAND PREDICTION

3.31 Introduction

The Kern County hydrologic system is complex and dynamic. The most dynamic element of this system is irrigation water applied to agricultural lands. This water may either be pumped from local groundwater basins, decreasing groundwater levels, or imported from other regions, thus increasing groundwater levels. At present, approximately 1,150,000 acre-feet of water is imported yearly through state and federal projects. The exact amount of groundwater pumpage is not known, nor is the total amount of irrigation water applied to the land. Estimates of these amounts are needed as inputs to the KCWA hydrologic model.

The most generalized method of estimating the total amount of irrigation water is to multiply the amount of irrigated cropland acreage by an empirically derived county-wide average application rate. As mentioned in the preceding crop identification section, substantial error can result if concentrations of specific crops occur. This is due to the differing irrigation requirements of specific crops.

A more specialized and more accurate procedure involves the utilization of the individual irrigation rates of different crops. In this method the amount of irrigated acreage for each crop is multiplied by each crop's specific irrigation rate, which is derived empirically through the observation of test plots. This results in crop-specific water demand predictions. The water demand estimates of each of the crops are then totaled to produce the total water demand prediction. After estimating the total water demand the amount of ground basin pumpage can be calculated by subtracting the amount of imported water from the total demand.

This study is presently focused on the Lost Hills Water District in Kern County. This district is advantageous for study because it is dependent on imported water for its irrigation; i.e., no groundwater pumpage is known to occur. The total amount of irrigation water used can thus be determined by examining canal records. This allows the district to be used as a test area for methods of predicting total water demand.

3.32 Goal

The objective of the GRSU is the development of techniques to predict total irrigation water demand and to determine its source. These techniques are being developed to operate on a nodal scale as required by the KCWA model. At present, the water prediction techniques

are being developed using highflight photography. However, the project is oriented towards the future development of more cost-effective techniques using LANDSAT imagery. Furthermore, the GRSU is developing and refining water prediction techniques in the Lost Hills district with the eventual goal of applying these techniques to the remaining districts in the hydrologic model area.

3.33 Methodology and Results

A wide spectrum of techniques has been investigated to generate water demand predictions. The procedures vary according to the generality of the data inputs. The most generalized method utilizes a county-wide average irrigation rate which is applied over several successive years to district-wide cropland acreage values. On the other end of the spectrum, the most specific procedure applies crop-specific irrigation rates to crop-type acreages, which have been measured annually on a nodal basis. The GRSU is investigating selected procedures from this range of possible techniques in order to determine and develop the optimum procedure.

3.331 Water Demand Prediction Based on Cropland Data

The most fundamental method being investigated by the GRSU entails the multiplication of the number of cropland acres by a county-wide average irrigation rate. This irrigation rate, 3.38 acre-feet/gross acre, has been derived from county-wide data on crop-type acreages and crop-specific average irrigation rates. The cropland acreage values used in this analysis have been obtained through croplands mapping using the highflight methodology documented in Section 3.1. GRSU personnel have mapped and measured cropland acreages in each node for the years 1971, 1972, 1973, and 1974. These acreage values have been multiplied by average irrigation rates to yield water demand predictions for each node for the years 1971 through 1974.

This method has consistently resulted in predictions which are overestimations (Table 3-9). Because of the consistency of these results in each of the nodes, the accuracy of the predictions can be improved by applying a corrective constant which minimizes the mean error of prediction. Corrective constants have been derived by comparing the water demand predictions for each year with their respective actual water deliveries, i.e., water delivery/water prediction proportions are calculated. In the case of overestimation, the proportion will be less than one; in the case of underestimation, the proportion will be greater than one. Proportion values for each year of historical data are averaged to produce the corrective constant. This value multiplied by the Kern County average irrigation rate produces a corrected irrigation rate. For example, the corrective

TABLE 3-9

LOST HILLS WATER DISTRICT:

WATER DEMAND PREDICTION USING THE KERN COUNTY AVERAGE

IRRIGATION RATE AND CROPLAND ACREAGES

% Error

	1971	1972	1973	1974
Node 2	+6%	+32%	+55%	+3%
Node 29	+24%	+8%	+11%	+36%
Node 30	+25%	+1%	+70%	+78%
District-Wide	+24%	+34%	+59%	+33%
Mean Error for All Years	38%			

Refined Predictions Utilizing Corrective Constants
(Corrective Constant Weighted by Acreages)

% Error

	Corrective Constant	Corrected Irrigation Rate	1971	1972	1973	1974
Node 2	.8247	2.787	-13%	+9%	+28%	-15%
Node 29	.8436	2.851	+4%	-9%	-6%	+15%
Node 30	.6857	2.318	-14%	-30%	+17%	+22%
District-Wide	.7426	2.510	-8%	0	+18%	-1%
Mean Error for All Years	7%					

constant for the district-wide prediction is .7426, which multiplied by the Kern County average irrigation rate (3.38 acre-feet/gross acre) produces the corrected rate of 2.51 acre-feet/gross acre. Using this rate results in an increase in accuracy of 31%.

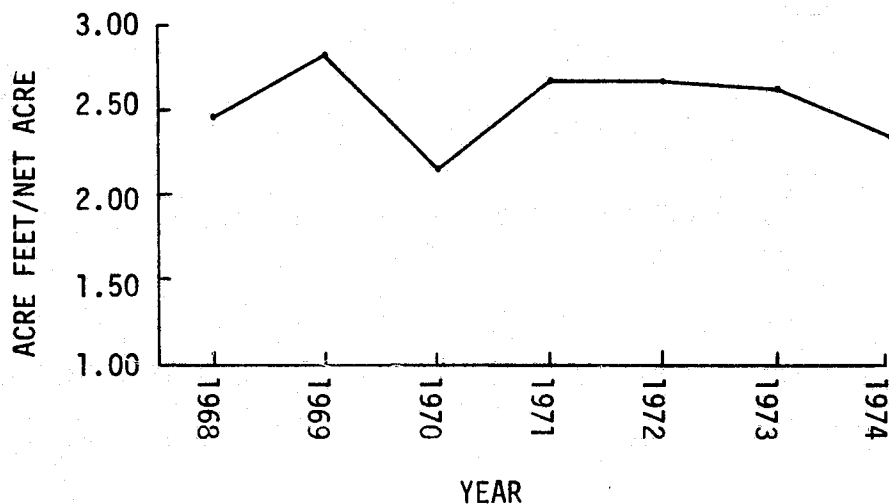
3.332 Water Demand Prediction Based on Crop Type Data

The overall crop pattern in a district is one of the most important factors in the accurate determination of water demand. Personnel of the GRSU have been investigating several methods of water demand prediction which take this factor into account. One procedure is the same as that previously described except that a 1969 Lost Hills average irrigation rate is applied to the cropland acreages instead of a Kern County average irrigation rate. This Lost Hills rate more accurately reflects the Lost Hills crop pattern, and accordingly, water demand predictions are more accurate. For the district predictions, accuracy increased 25% over the previous cropland predictions (without corrective constants).

The above method takes into account the particular crop pattern in Lost Hills. However, this method does not account for change in that pattern as it involves the application of a 1969 irrigation rate to the years 1971 through 1974. The crop pattern in Lost Hills is continually changing, as is the average irrigation rate. (Figure 3-7). Assuming that there is a trend in this change, a decrease in accuracy would be expected as the average irrigation rate being applied becomes increasingly outdated. An invariable trend in the change in crop pattern or average irrigation rates does not exist but Table 3-9 does reveal a general decline in accuracy as the 1969 average irrigation rate becomes increasingly out-of-date.

GRSU personnel have also investigated water demand prediction techniques that account for changing crop patterns. One such method utilizes the yearly acreage values for each crop multiplied by their respective irrigation rates. The resulting values are then totaled to produce the yearly estimates of total water demand. The crop acreage values used were obtained through ground sampling by personnel of the Lost Hills Water District. These crop acreage values were sampled on a district-wide basis so that preliminary predictions have had to be made on a district scale. Using the available data, predictions have been produced for the Lost Hills district for the years 1969 through 1974. As shown in Table 3-10 accuracies are better than those obtained using previously discussed methods. This suggests the potential need for yearly crop data in predicting water demand. The consistency of the results allows the application of a corrective constant to refine the estimations. In this case, the corrective constant (1.1158) is multiplied by the estimation values to produce refined estimations (Table 3-10). The resulting accuracy, 95.7% (100%-4.3%), is only 2.7% better than the refined croplands estimate; but in districts with ground water pumpage the calculation of reliable corrective ratios will not be possible.

LOST HILLS WATER DISTRICT
AVERAGE IRRIGATION RATE 1968 - 1974



LOST HILLS WATER DISTRICT CROP BREAKDOWN 1968-1974
 (% of Total Cropland Acreage)

CROP	1968	1969	1970	1971	1972	1973	1974
Alfalfa Hay	-	-	2%	2	4	4	5
Alfalfa Seed	13	29	22	7	-	-	-
Almonds	-	T	T	-	-	1	2
Barley	4	3	4	2	1	2	23
Beets	-	T	-	-	-	-	-
Black-eyes	5	-	T	-	-	T	-
Carrots	-	1	T	-	-	T	-
Cotton	30	27	33	45	61	65	48
Figs	1	2	2	1	1	1	1
Lettuce	-	T	-	-	-	T	1
Melons	-	3	1	-	-	-	-
Milo	40	18	-	-	T	-	T
Okra Seed	-	T	-	-	-	-	-
Olives	-	1	14	17	16	14	9
Peppers	T*	-	-	-	-	-	-
Pistachios	-	-	1	2	9	8	7
Potatoes	-	1	T	-	-	-	-
Safflower	-	4	-	-	-	-	-
Sugar Beets	5	6	19	22	4	-	-
Tomatoes	3	1	-	-	-	-	-
Vines	-	-	-	1	4	3	2
Watermelons	-	T	-	-	-	-	-
Wheat	-	3	2	1	-	T	2
Test Crops	-	T	-	-	-	-	-
Onions	-	-	-	-	-	-	T

* T = trace

FIGURE 3-7. Change in crop pattern and average irrigation rate for Lost Hills Water District, 1968-1974.

TABLE 3-10

ACCURACY OF WATER DEMAND ESTIMATIONS DERIVED USING ANNUAL
LOST HILLS DISTRICT CROP DATA (in Acre-Feet)

	1969	1970	1971	1972	1973	1974
Predicted Water Demand	29,994	30,750	66,892	77,530	87,963	112,614
Actual Water Demand	29,600	32,129	73,995	86,711	102,400	127,848
Error	394	1,379	7,103	9,181	14,437	15,234
% Error	+1.3%	-4.3%	-9.6%	-10.6%	-14.1%	-11.9%
Mean Error for All Years	8.6%					

ACCURACY OF WATER DEMAND ESTIMATIONS DERIVED USING ANNUAL
LOST HILLS DISTRICT CROP DATA AND USING A
CORRECTIVE CONSTANT OF 1.1158 (in Acre-Feet)

	1969	1970	1971	1972	1973	1974
Predicted Water Demand	33,461	34,305	74,625	86,492	98,132	125,632
Actual Water Demand	29,600	32,129	73,995	86,711	102,400	127,848
Error	3,861	2,176	630	219	4,268	2,216
% Error	+13.0%	+6.8%	+0.1%	-0.2%	-4.2%	-1.7%
Mean Error for All Years	4.3%					

Data for the KCWA hydrologic model is to be generated on a nodal basis. Because of this, the procedure utilizing annual crop data is being further developed to operate on a nodal scale. At present, the nodal crop acreage data is being derived from KCWA crop survey maps. However, the prediction techniques will be developed for future use with crop acreage data derived from LANDSAT-type imagery.

The preliminary results of GRSU research into water demand prediction procedures are encouraging. Accuracies of the district water demand predictions generally exceed 90%. However, some initial nodal results show large variations in accuracy. Although the crop breakdown and acreages in a node are probably the most important factors determining its water demand, there are many other factors which have to be considered. The GRSU is presently investigating the importance of agricultural practices such as land preparation, fallowing and dry-farming. These activities can be misinterpreted on highflight photography as irrigated agriculture, thus causing water demand estimations to be too large in the nodes where these activities occur. It is expected that mapping procedures using multi-date LANDSAT imagery will generally eliminate this problem. The GRSU is also investigating the possible occurrence of groundwater pumpage. If groundwater pumping is occurring in any of the Lost Hills nodes, this will directly effect our accuracy values for that node.

Inclusion of such factors, which have varying effects on different nodes, in a water demand prediction procedure is expected to produce nodal predictions which are more accurate and consistent than previously obtainable. GRSU research during the next period will be focused on consideration of these factors and on the refinement of prediction techniques to operate on a nodal scale in the Lost Hills and other Kern County Water Districts.

3.40 CLOUD COVER ANALYSIS

3.41 Introduction

The quality and extent of useable imagery sensed in the visible and near infrared region of the electromagnetic spectrum are directly related to the amount of cloud cover present in the scene. The lack of cloud cover penetration in this region degrades the utility of imagery containing cloud cover whenever such imagery is being utilized for land use or related analyses. As common experience would suggest, cloud cover varies both spatially and temporally and only probabilistic statements can be made concerning its occurrence at any particular place and point in time. Knowledge of the probabilities associated with obtaining imagery with given cloud cover conditions should directly aid in the evaluation of various remote sensing methodologies for specific applications. Additionally, the generation of such information concerning our study region in Kern County has

added to our overall knowledge of this region's environmental parameters.

3.42 Goal

The purpose of this research topic is to 1) empirically document cloud cover conditions in Kern County, and 2) develop an analysis methodology whereby the information requirements of specific remote sensing applications can be evaluated in terms of the imagery obtainable from various remote sensing systems and configurations (e.g., single or multiple earth resource satellites, high altitude aircraft platforms, etc.).

3.43 Methodology

This examination of cloud cover in Kern County has been oriented towards the following parameters:

1. Data Sample Size: In order to minimize data collection, and therefore increase the utility of the analysis procedure for other users, various data sample sizes were compared. An examination of all data available for the test area of Kern County (22 years of meteorological records) showed that a 10 year period is sufficiently similar to a 20 year period to justify its use as a valid data base.

2. Data Reduction: Data was collected on a daily basis for the daylight hours of highest sun angle (0900-1400 hours). For the analysis of satellite imagery the data was summarized on a monthly basis utilizing only data for the hour 1000, corresponding most closely to the time of LANDSAT overpasses in Kern County. Analysis of the data for high altitude imagery will be done on a daily basis utilizing specific hours, since flight missions can be planned specific to the hour and day.

3. Scene Visibility Threshold: Cloud cover is calibrated on a scale of 0-10 with 0 denoting a clear sky. Due to the requirements for high scene visibility 0-2 cloud cover was selected as acceptable for an agricultural study threshold.

3.44 Results

3.441 Application Information Requirements

The seasonal time frame used for each cloud cover study depends upon the informational requirements of specific applications. Two example applications are included here to demonstrate the utility of the analysis methodology. The first example is croplands mapping (as discussed in a separate section), which requires a minimum of 1

¹ Source: U.S. Department of Commerce, N.O.A.A., Environmental Data Service. Local Climatological Data, obtained from National Weather Service, Bakersfield, California.

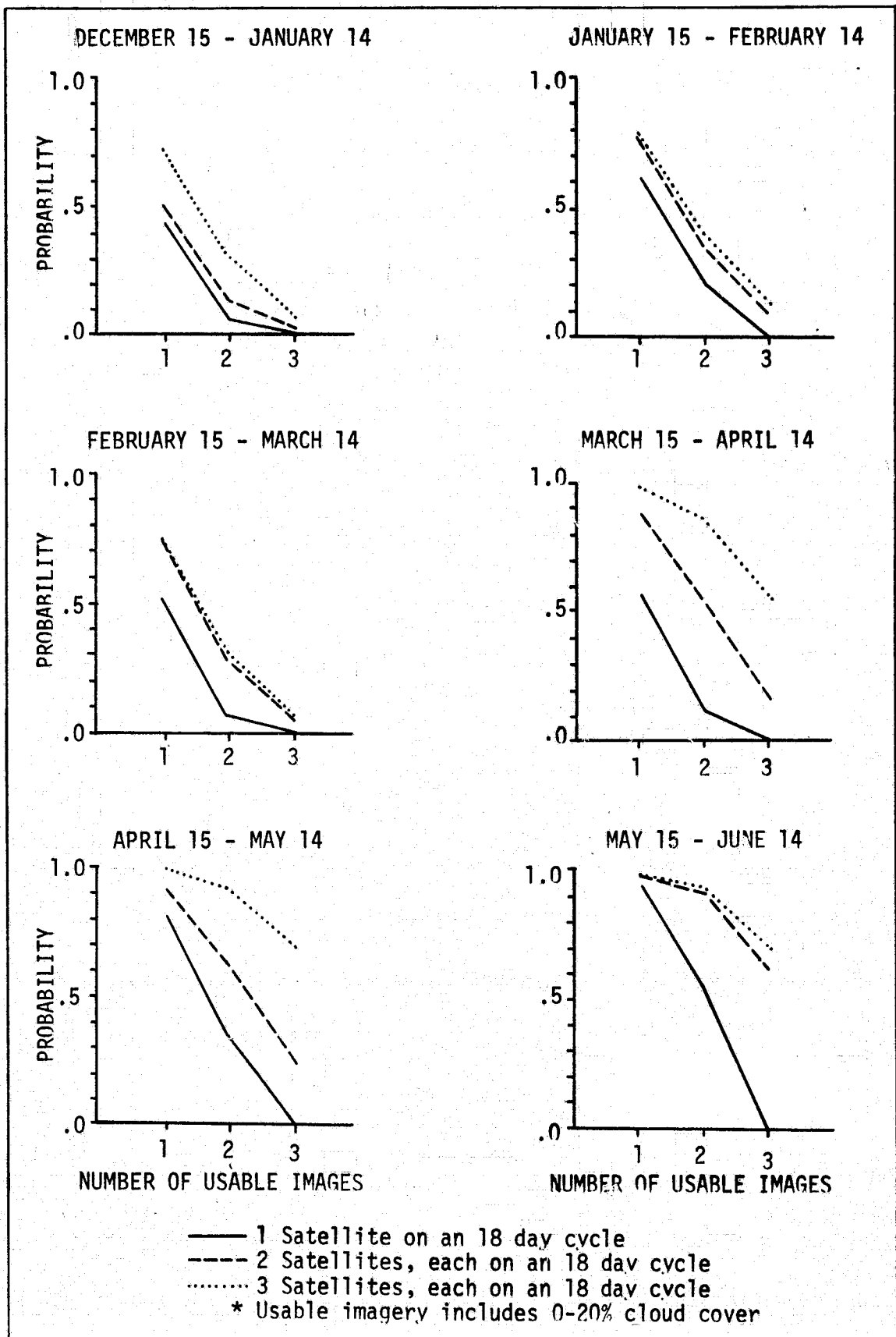
TABLE 3-11
PROBABILITY OF OBTAINING USABLE SATELLITE IMAGERY*
FOR KERN COUNTY

CROPLAND MAPPING	1 SATELLITE ON AN 18 DAY CYCLE			2 SATELLITES EACH ON A DIFFERENT 18 DAY CYCLE			3 SATELLITES EACH ON A DIFFERENT 18 DAY CYCLE		
	1 USABLE	2 USABLE	3 USABLE	1 USABLE	2 USABLE	3 USABLE	1 USABLE	2 USABLE	3 USABLE
June 1 - July 11	.9934	.8581	.1509	.9998	.9984	.9753	1.0000	.9992	.9911
July 12 - Aug. 20	.9289	.5782	.1029	.9985	.9775	.8567	1.0000	.9984	.9844
Aug. 21 - Sept. 30	.9855	.8017	.1908	.9987	.9443	.9406	1.0000	.9998	.9978
June 1 - July 31	.9956	.9341	.6407	1.0000	.9993	.9917	.9999	1.0000	1.0000
Aug. 1 - Sept. 30	.9971	.9531	.7176	1.0000	.9998	.9971	1.0000	1.0000	1.0000
June 1 - Sept. 30	1.0000	.9996	.9931	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Aug. 1 - Aug. 31	.9227	.4993	n.a.+	.9992	.9806	.8213	.9998	.9958	.9595
COTTON INVENTORY AND PLOWDOWN MONITORING									
Dec. 15 - Jan. 14	.4342	.0589	n.a.	.4982	.1326	.0130	.7052	.3004	.0750
Jan. 15 - Feb. 14	.6250	.2000	n.a.	.7735	.3594	.0848	.7746	.3870	.1333
Feb. 15 - Mar. 14	.5200	.8000	n.a.	.7349	.2973	.0513	.7144	.3057	.0727
Mar. 15 - Apr. 14	.5793	.1177	n.a.	.8797	.5261	.1623	.9705	.8242	.5281
Apr. 15 - May 14	.8248	.3591	n.a.	.9182	.6194	.2328	.9898	.9130	.6826
May 15 - June 14	.9585	.5545	n.a.	.9946	.9267	.6349	.9915	.9247	.7131

* Usable imagery includes 0-20% cloud cover

+ Not applicable

FIGURE 3-8
PROBABILITY OF OBTAINING USABLE SATELLITE IMAGERY*
FOR COTTON INVENTORY AND PLOWDOWN MONITORING



good image with increasing accuracy for each successive image during the period of June 1 to approximately October 1. The second example is cotton mapping and plowdown monitoring (also discussed in a separate section), which requires cotton identification by June 15 and plowdown information between December 15 and January 15.

3.442 Remote Sensing System Configuration

The response flexibility of a remote sensing system to cloud cover will vary according to each system's configuration. Satellite imagery such as LANDSAT is received on a predetermined daily and sun synchronized cycle, thus allowing no adaptability to weather conditions. Only by increasing the number of overpasses (through the use of multiple satellites or more frequent cycles) can the probability of obtaining clear images be increased for such a system configuration.

High altitude imagery is more easily adaptable to variable weather conditions as flight missions can be planned for specific days, thus essentially avoiding cloud cover. Accordingly, the application of the cloud cover analysis methodology to highflight imagery must consider daily rather than monthly or seasonal cloud cover.

3.443 Croplands Mapping and Cotton Example

The development of the methodology is at a point where analysis can be made of the impact of cloud cover on imagery for any number of satellite systems during any time period of the year. Any land use application of satellite imagery can make use of this analysis by supplying a time frame, the number of images required, and the visibility threshold (from 0-10) of the imagery. Table 3-11 summarizes the results of such an analysis for the croplands mapping and cotton inventory and plowdown monitoring methodology (Section 3.1). Figure 3-8 demonstrates graphically the ability of 1, 2, and 3 satellites to obtain useable imagery for cotton inventory and plowdown mapping.

Future work on this analysis methodology will include the study of cloud cover relationships to high altitude imagery application requirements. More specifically, this will entail a study of the optimum daily hours of visibility for each month and a more extensive study of probabilities for shorter time periods, as required by various applications. In addition, further simplification of the data for use in the probability equation to improve its utility for all users will be examined.

3.50 SALINITY

3.51 Introduction

The Kern County area has salinity problems common to many arid environments. Under humid conditions soluble salts originally

present in soil materials and those formed by the weathering of minerals are generally leached downward into the groundwater and ultimately transported by streams to oceans. Saline soils are therefore practically nonexistent in humid regions. Although weathering of primary minerals is the indirect source of nearly all soluble salts, there are few instances where sufficient salts have accumulated from this source alone to form a saline soil. Instead, saline soils generally occur in areas that receive salts from other locations with surface of groundwater as the primary carrier. In arid regions water used for irrigation may contain from 0.1 to as much as 5 tons of salt per acre-foot of water, while the annual application of water may amount to 5 feet or more. Therefore, large quantities of soluble salts may be added to irrigated soils over relatively short periods of time. In Kern County considerable expense has been taken to route irrigation waters onto the lands; presently, however, only minimal consideration has been directed toward the removal of saline drainage water from the land. In many arid regions, when bringing new lands under irrigation, farmers have frequently failed to recognize the need for establishing artificial drains to care for the additional water and soluble salts.

In Kern County the groundwater movement of salt-bearing waters away from topographically higher lands raises the groundwater level of lower lying areas, and can result in the temporary flooding of an area when enough water and/or subsurface aquaclude are present. Sub-surface aquacludes may cause local perching of water tables. These perched water tables arise when a tongue or lens of impermeable fine-grained material restrains the normal downward percolation of groundwater. When these aquacludes have a slope component, as with the westward sloping alluvial fans from the Sierra Nevada Range in Kern County, the groundwater will tend to migrate under the influence of gravity and accumulate in topographic lows. This downslope migration of groundwater is analogous to surface water flowage. If impermeability is severe enough and the aquaclude relatively near the surface, water will occasionally even pond on the surface during times of high water input. Under such conditions the upward movement of soluble salts from saline groundwater or the evaporation of surface water may result in the deposition of soluble salts. In our study area along the west side of the San Joaquin Valley, because of the presence of both aquacludes and large scale irrigation, both groundwater and irrigation water may contribute to the salinization of the soil.

In any effective land management program in an arid region the salinity variable must be given significant attention, especially in regards to water resource management. For an effective management plan to be developed an accurate inventory of the areal distribution of saline soils is needed. However, the most recent county-wide soil survey was conducted over 12 years ago by the Department of Water Resources and is in need of revision in terms of the locational

expansion of saline-alkali soils.

A major responsibility of the KCWA is to inform its water users concerning preventative water management techniques. KCWA dispenses information to users concerning techniques such as tiling, leaching and drainage to improve soil productivity. In conjunction with these activities, KCWA requires data which will serve the following purposes:

1. Locate those agricultural areas that are, at present, suffering the most severe salinity related stress. Such areas would be designated as priority areas in terms of the application of leaching and/or drainage water management measures.
2. Plot the distribution of salt damaged areas in relation to topographic relief, soils, geology, and proximity to natural drainage channels. Such data will enable KCWA to select the optimum locations for a series of lateral drains that will be designed in such a manner as to alleviate both the perched water and salinity problems for many areas.
3. Provide soil salinity data on a nodal basis which will serve as input to the KCWA Hydrologic Model.
4. Finally, as additional information, KCWA and other agencies would like to locate those areas of natural vegetation that are not in cropland because of excessive concentrations of salts but which could be brought into production if proper leaching and drainage practices were implemented. In Kern County every acre of land brought into production generates, on the average, an income of approximately \$800 per year. (The crop value of a section of land would therefore be approximately \$500,000).

3.52 Goal

With respect to this phase of our integrated study the goal of the GRSU is to develop a methodology whereby remote sensing techniques can inventory and monitor soil salinity in the KCWA area. A predictive technique is being developed in order to facilitate the estimation of soil salinity as well as monitor subtle changes in soil salinity on a regional basis both spatially and temporally. This predictive technique will use crop identification data in combination with actual field sampled salinity data, damage data, and known crop salt tolerance thresholds as input variables. In conjunction with this work GRSU personnel are exploring the development of photographic keys for individual crops at various levels of salt concentrations and at various periods in their phenological cycles.

In addition to the above research, GRSU will be generating salinity data that will "drive" the KCWA model to determine the additional

amount of water that will be demanded to maintain productive land and reclaim unproductive saline land by leaching. The overriding goal of our research in this area is the detection of the presence, or changes in the level, of soil salinity in a given region before they become a serious management problem. If successful, the methodology developed could easily be applied to many other similar arid agricultural environments.

3.53 Methodology

General Field Methodology: For the purposes of this report a "saline" soil will be defined as a soil which has an electrical conductivity of its saturation extract (Ece)¹ of more than 4 mmhos/cm adjusted to 25 degrees C., the exchangeable-sodium-percentage is less than 15, and the pH is less than 8.5.

The December 31, 1974 Progress Report fully documented the field methodology used for two initial sampling efforts. On both of these field data acquisition missions soil samples were returned to Santa Barbara where salinity was determined by measuring the electrical conductivity of the soil extract. The electrical conductance "EC" is the most suitable measure of salinity because readings increase as the soluble salt content of the soil increases. The opposite is true if electrical resistance measurements are made. Therefore, electrical conductance, which is the reciprocal of resistance, simplifies the interpretation of the readings.

The procedure for measuring soil salinity involves preparing a saturated soil paste by stirring in distilled water until a characteristic endpoint is reached. A suction filter is then used to obtain a sufficient amount of the extract for making the conductivity measurement. Soil pH was also measured for each saturated soil paste sample. These data are significant because when coupled with the Ece readings pH can determine whether the soil is saline, saline/alkali, or non-saline/alkali. To review briefly, saline soils have an Ece value greater than 4 mmhos/cm at 25° C. and the exchangeable-sodium-percentage is less than 15. Saline/alkali soils have an Ece value greater than 4 mmhos/cm at 25° C., and the exchangeable-sodium-percentage is greater than 15. Non-saline/alkali soils exist when exchangeable-sodium-percentage is greater than 15 and the Ece is less than 4 mmhos/cm at 25° C.

PH values of 8.5 are usually required to indicate an exchangeable-sodium-percentage of 15 or more. Soils having pH values of less than 7.5 almost always contain no alkaline-earth carbonates and those having values of less than 7.0 contain significant amounts of exchangeable

¹ Ece represents Electrical Conductivity of the soil Extract measured in millimhos/cm adjusted to 25° centigrade.

hydrogen. None of the pH samples that were taken had a pH reading of greater than 6.0.

3.54 Interpretation and Compilation of a Salinity Damage Map

KCWA requested that the GRSU identify areas of salinity stress within our study area. Based upon this request a salinity damage map was produced. This information is being used by KCWA as justification for the reactivation of a Central Valley master drain proposal. KCWA is literally going door-to-door with the results of our investigations appraising land owners of the problem areas.

To compile the salinity damage map, trained image interpreters were assigned the task of identifying and mapping those agricultural areas of Kern County which were undergoing salinity stress. This interpretation was made from multi-date CIR 1:125,000 scale photography with April, 1974 being the most recent date of imagery employed in the analysis. Figure 3-5 in the December 31, 1974 Progress Report depicts a representative sample of the KCWA area (transect Highway 119) in terms of crop type, salinity damage, soil type, and color infrared signature. Interpreters identified, on a field-by-field basis, the percentage of each field that expressed salinity stress (Figure 3-9). This analysis included damage to croplands as well as areas of natural vegetation. It is acknowledged that the stress categorized as salinity damage may in reality be due to other factors, e.g., improper water application procedures, disease, etc.; however, salinity damage represents the major agent for yield decrement in Kern County and produces highly diagnostic stress signatures.

Interpreters used two major surrogates to aid in the identification of the salinity stressed fields: native vegetation and crop cover. Many areas of natural vegetation are covered by extensive caliche deposits. There is no question regarding the salinity of these areas which typically show up in the 50-100% category on the damage map. In several areas of natural vegetation, however, the presence of halophytic vegetation created an interpretation problem by masking the true salinity condition. It was found that this problem could be overcome by field checking and by exploiting the fact that in Kern County naturally vegetated areas tended to be nucleated in areal extent. GRSU personnel have done extensive field sampling in these areas of native vegetation/caliche and are confident of their interpretation.

The second and major method of identifying salinity stress was to examine the agricultural crop cover. Multidate imagery analysis techniques were used to assure the presence of crops in most fields. Hot-spot scalding, caliche deposits, and a mottled appearance of the crop cover represented the major image interpretation surrogates used to detect salinity damage. The ability of interpreters to identify and

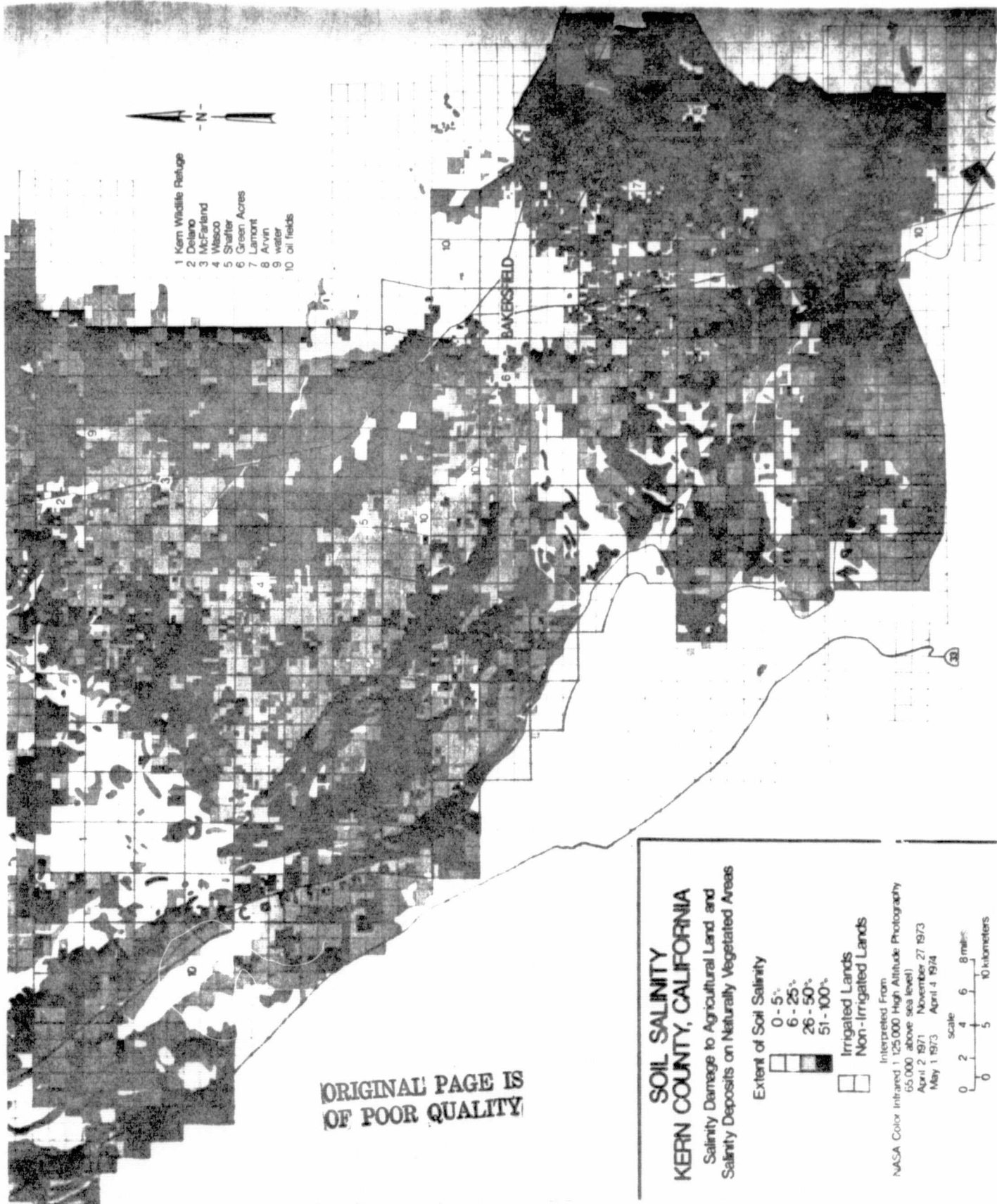


FIGURE 3-5. Salinity Damage Map of Kern County.

accurately classify those areas undergoing salinity stress was possible owing largely to the program of interpreter training based on extensive ground truthing undertaken by GRSU personnel. Five transects with the known crop type, soil type, and salinity data allowed the interpreters to use this regional information to train their manual classification procedure. It is significant to note that in many instances a field may be excessively saline but, with a salt tolerant crop growing on it, e.g., cotton, the field may show only moderate damage. However, if a nontolerant crop, e.g., beans, were to be planted on the same field it should register more extensive damage. This characteristic will be considered in more detail in the salinity prediction discussion.

Probably the greatest handicap encountered in compiling the Kern County Soil Salinity Map was the interpretation of salinity damage for bare soil agricultural fields. As might be expected there are optimum time periods throughout the year when a maximum percentage of the fields in Kern County are being cultivated and have crop cover. For Kern County this has been determined to be the month of August. It has also been concluded that the best time for determining salinity stress was in the early stages of the phenological cycle. The relatively young fields do not possess a coalescing canopy of vegetation complete enough to mask the effects of salinity.

At present the greatest problem encountered is the point sampling methodology used to gather ground truthed salinity values. In Figure 3-10 it is evident that the correlation between the damage class and the actual point salinity values is not consistent. Examination of the 50-100% damage class shows that actual field sampled salinity values as low as 0.2 (Ece) have been classified in this category. Although a general increasing trend exists from the lower to higher damage classes, the extreme overlap of the higher damage classes upon the lower classes (especially in the lower soil salinity values, where all damage classes include salinity values ≤ 1 mmhos/cm Ece) was not expected. Field sampling to date suggests that this is the result of the variable distribution of salinity.

As part of our effort to evaluate the nature, extent, and variability of salinity distributions and their associated problems, GRSU has recently undertaken an intensive field sampling effort in a limited geographic region. To date, 13 fields, each approximately 160 acres in size, have been intensively sampled. Figure 3-11 depicts one of these intensively sampled fields and shows the wide variation of salinity values that can be found within a single field. In this particular example the mean salinity value for all samples taken is 7.2 Ece, while individual readings range from 0.6 to 47.0. One purpose of this intensive sampling is to accurately document field salinity distributions in such a manner that a sampling methodology can be developed making optimum use of field investigation efforts. An

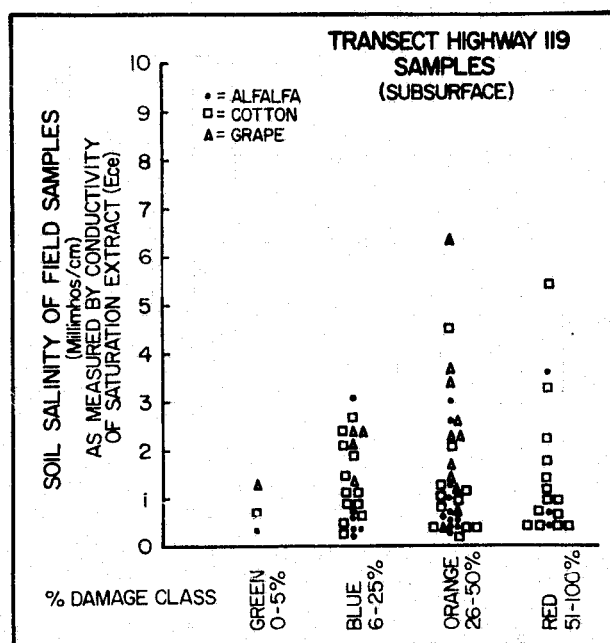


FIGURE 3-10. Subsurface soil salinity samples taken along transect Highway 119 and the corresponding damage classification.

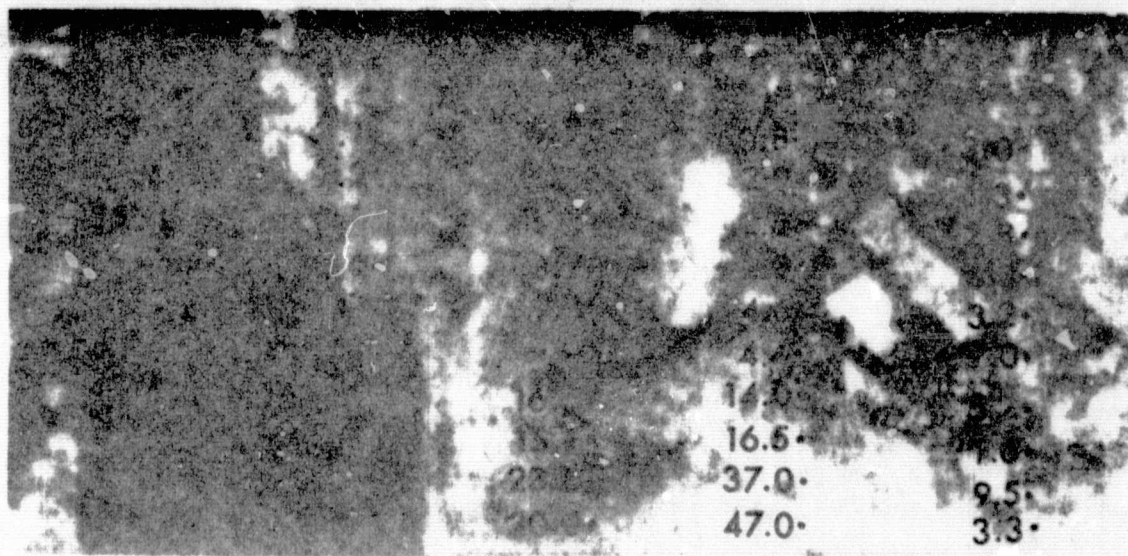
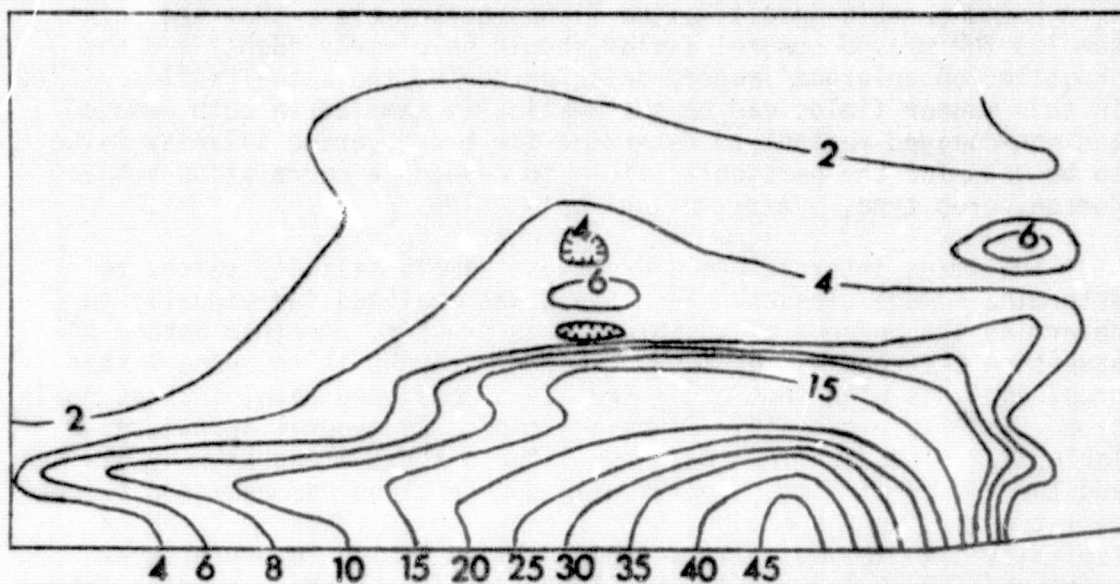


FIGURE 3-11. Salinity (Ece) contour map compiled from intensive point sampling of a cotton field in the Goose Lake area of Kern County.

even more important use of this data is its input into a remote sensing methodology that presently appears capable of predicting field average soil salinities within our study area by using crop damage as a surrogate.

Based on this investigation it has become clear that the point samples for ground control fields should be clearly identified and annotated on enlarged imagery prior or during the actual soil sampling. In this manner fields can be systematically sampled in both damaged and non-damaged regions to determine the best average salinity value to be used for the particular field to develop a correlation between damage, crop type, yield and salinity value.

The image interpreters did not use sample salinity values to determine damage classes. Each field was analyzed individually to determine the percent of visible damage present. Another method of assessing the accuracy of the percent damage map is to compare this areal analysis with some other areally dimensioned data, such as soil type. Soil type classifications are typically general in nature. Table 3-12 plots the four major soil types found along Highway 119 and the number of times a particular damage class was assigned to each soil type. Upon inspection, 59% of the samples taken in Tx-PH (a typically high saline soil) were classified by the interpreter as being red (50-100% damage). Similarly, 21-47% of these samples taken within the Cd-TD (a low potential saline soil) region were found to exhibit green and blue (0-25%) damage. When one considers that almost 75% of the 25-100% damage occurs in Tx-PH soil, which has the highest potential for salinity, the interpreter is certainly approaching an acceptable standard of classification accuracy. Present research activities include the documentation of these accuracies.

3.55 Salinity Prediction

At present, conventional techniques for gathering salinity data in agricultural environments involve costly field sampling procedures. GRSU is developing a remote sensing methodology whereby salinity data may be generated on a per field basis from high altitude photography. Such data can serve as input to hydrology models by providing an estimate of the amount of water necessary to effectively leach saline soils and keep land in economic production.

The basic hypothesis of the salinity prediction procedure is that there is a correlation between the condition and type of crop present in a field and the soil salinity of that field. The University of California Agricultural Extension Service has published reports which state the yield decrement to be expected from certain crops due to specific soil salinity values. Table 3-13 depicts the 0%, 10%, 25%, 50% yield decrement threshold values for the major crops found in Kern County. Yield decrement data compiled jointly by KCWA and

TABLE 3-12

Soil Types and Damage Classes for Salinity Samples Along
Transect Highway 119

		SOIL TYPE			
		<u>High Salinity Potential</u>		<u>Low Salinity Potential</u>	
		Tx-PH	Gw-HL	HL-HD	Cd-Td
% SALINITY DAMAGE	RED 51-100%	(10)* <u>59%</u>	(12) <u>29%</u>	(7) <u>26%</u>	(2) 11%
	ORANGE 26-50%	(4) <u>24%</u>	(10) <u>24%</u>	(7) <u>26%</u>	(4) <u>21%</u>
	BLUE 6-25%	(2) 12%	(15) <u>36%</u>	(11) <u>41%</u>	(9) <u>47%</u>
	GREEN 0-5%	(1) 6%	(5) 12%	(2) 7%	(4) <u>21%</u>

* (10) = number of fields

TABLE 3-13

YIELD DECREMENT TO BE EXPECTED FOR
CERTAIN CROPS DUE TO SOIL SALINITY*

	0%	10%	25%	50%
<u>Crop</u>	<u>Ece</u>	<u>Ece</u>	<u>Ece</u>	<u>Ece</u>
Barley	8	12	16	18
Sugarbeets	6.7	10	13	16
Cotton	6.7	10	12	16
Safflower	5.3	8	11	14
Wheat	4.7	7	10	14
Sorghum	4	6	9	12
Soybean	3.7	5.5	7	9
Rice (paddy)	3.3	5	6	8
Corn	3.3	5	6	7
Beans (field)	1	1.5	2	3.5
Beets	5.3	8	10	12
Tomato	2.7	4	6.5	8
Barley (hay)	5.3	8	11	13.5
Alfalfa	2	3	5	8
Grape (Thompson)	2.7	4	-	8
Almond	1.7	2.5	-	5
Peach	1.7	2.5	-	5

*University of California Agricultural Extension Service, Kern Crop Information, U.S. Department of Agriculture, November 15, 1973.

Ece is defined as the electrical conductivity of a saturation extract in millimhos per centimeter (mmho/cm).

GRSU personnel for 13 cotton fields totaling 2,080 acres substantiates the existence of a negative correlation ($r = -.76$) between salinity and crop yield in our study region. This data is presented in Figure 3-12.

Assuming that a given distribution of salinity exists, one would expect that in areas of higher soil salinity farmers would tend to plant the more salt tolerant crops. This "natural" crop selection process may occur even though the farmers are not cognitively aware of the saline condition. Figure 3-13 indicates that a general tendency does exist in this direction, i.e., tolerant crops tend to be planted in the more saline regions.

The assumption that there is a correlation between crop type and soil salinity becomes more complicated in low saline areas. Salt tolerant crops, e.g., cotton, barley etc. can be planted not only on the saline soils but also on non-saline soils. Cotton, a major example because of its predominance, can be planted on both the best and poorest soils in the valley, a fact which complicates the original hypothesis.

A method which has potential for alleviating part of this problem entails the inclusion of another variable in the analysis, viz. crop damage. If both crop type and crop damage are known for a specific field, then a refined prediction may be made in terms of soil salinity. Figure 3-14 is a theoretical diagram for which three crops i.e., beans, sorghum, and barley have their 0% yield decrement threshold limit, hypothetical field sample salinity value, and damage assessment given. If planted barley exhibits a yield decrement (damage) whenever its threshold value of 8 millimhos Ece is exceeded, our tests to date indicate that the interpreter will classify this field as being damaged. If the field expresses no damage, then the assumption must be that the salinity value is less than 8 millimhos Ece. If the actual ground truth salinity value for the field was 9 millimhos Ece, then the prediction error based on crop type would be -1. However, since damage is expressed, an incremental value could be added to the threshold value. In this case 1 millimhos unit, the ideal corrective value, has been added making a refined salinity prediction of 9 millimhos Ece and a prediction error of 0. More research needs to be accomplished in order to evaluate just how much of an Ece increment should be assessed as corresponding to each level of damage, and how accurate the resulting prediction will be.

GRSU has recently shifted its emphasis from determining the specific magnitude of the Ece increment to developing a more rigorous quantitative evaluation of the salinity damage which can be correlated directly with the true soil salinity value and/or yield decrement. Our initial research efforts in this area have been directed solely at fields of cotton as this eliminates the variable of several potential expressions of salinity damage. If successful, and preliminary

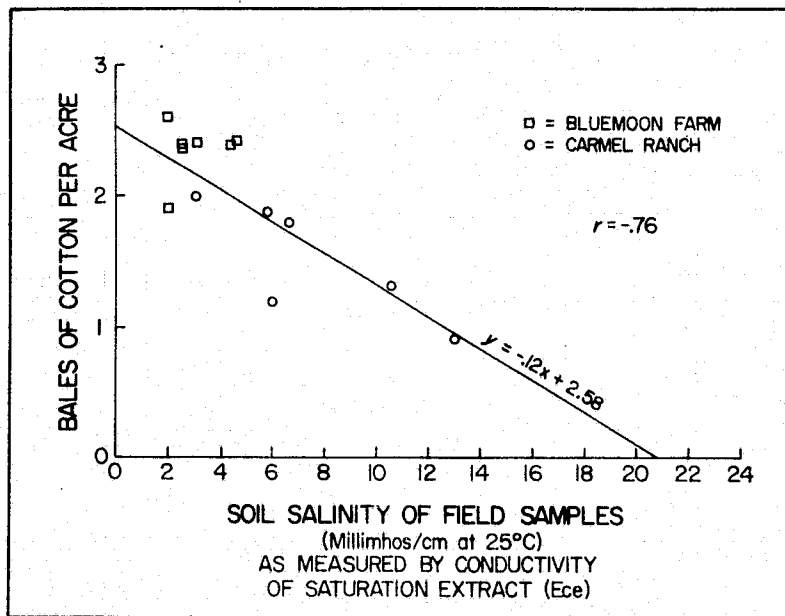


FIGURE 3-12. Correlation between cotton yield decrement and soil salinity, Kern County, California.

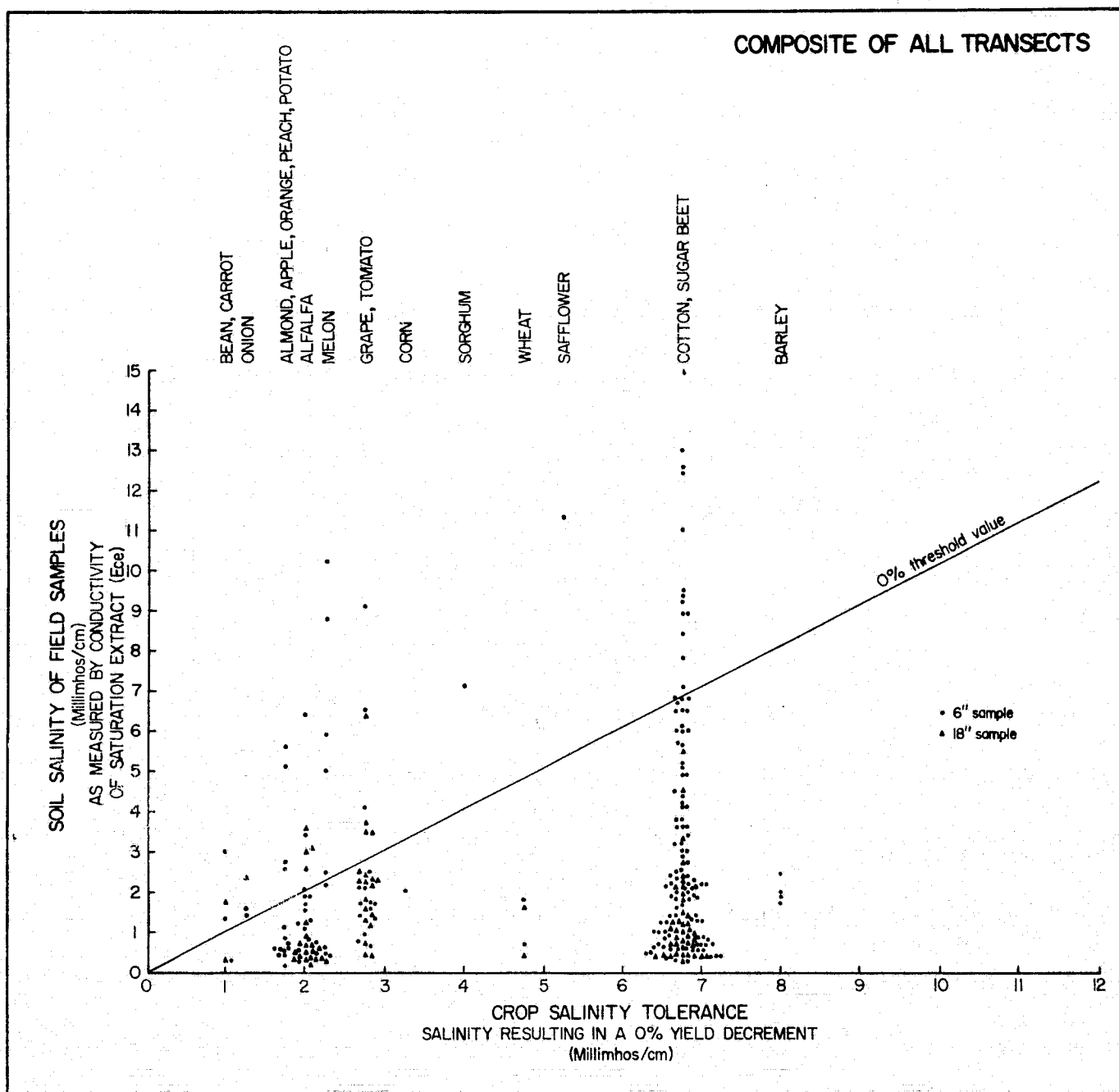


FIGURE 3-13. Composite of 5 transects showing the value of the soil salinity field samples and the crop salinity tolerance above which a yield decrement will result for each crop type. The values in this figure indicate a tendency toward the planting of more salt tolerant crops in areas of greater soil salinity. These figures, however, should be considered preliminary owing to the problems of variability of salinity distributions within individual fields as related to point soil sample readings, discussed in the text.

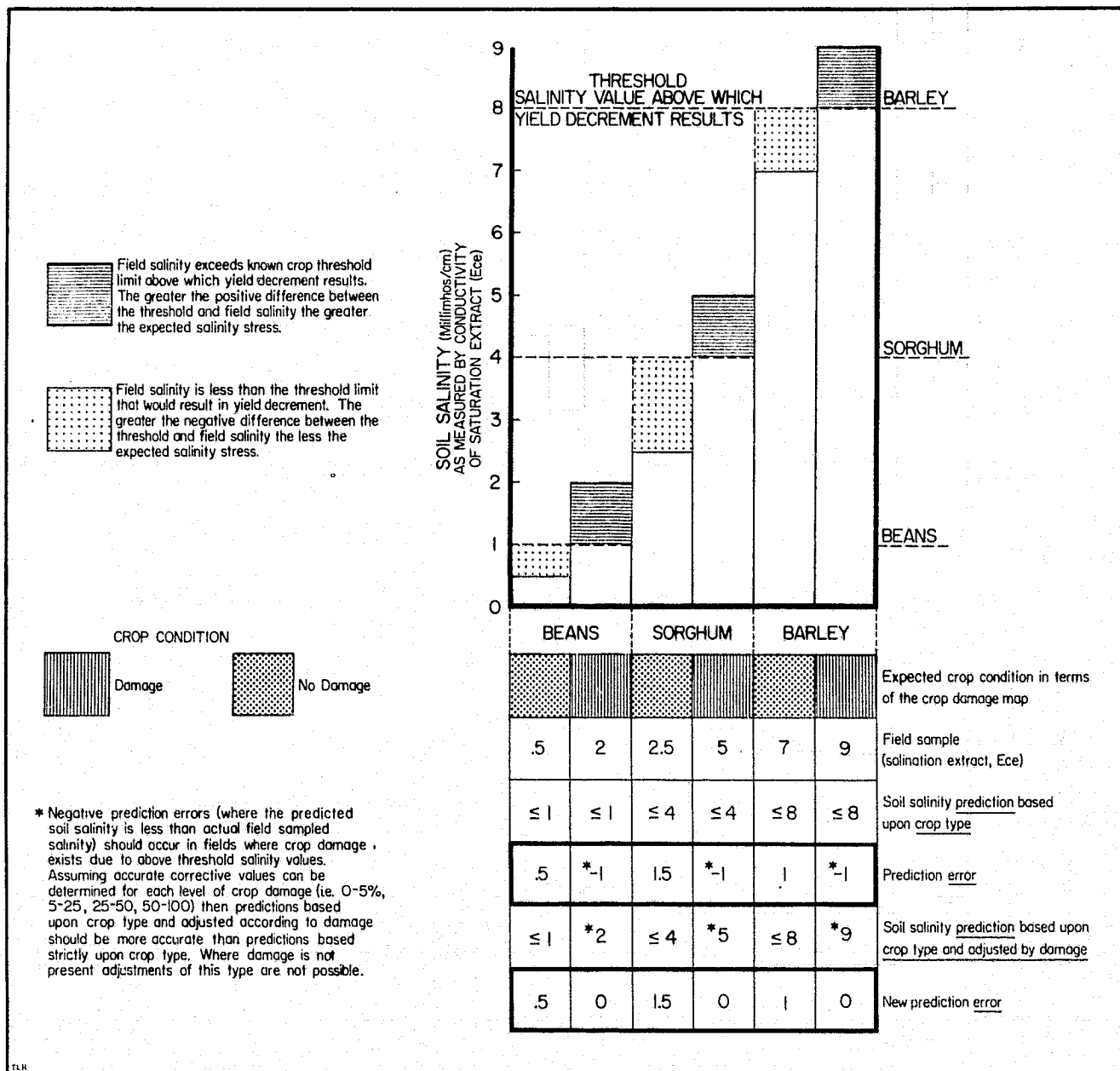


FIGURE 3-14. Salinity prediction theory diagram.

results are definitely encouraging, other crops will be examined using the same methodology.

Several of our preliminary attempts at quantifying damage were hampered by the range of tonal values exhibited by healthy fields. This range of values can be attributed to any one or a combination of variables including: the various sun angles between individual fields and the observation platform; vignetting effect of the camera lens; soil type variations (including but not limited to soil salinity); and differing cultivation practices, e.g., fertilization, irrigation, etc. To reduce the effects of variations attributed to these variables a procedure has been developed whereby a "healthy" portion of each field is selected and used as the basis for quantifying damage in the remaining portion of the field. Each field is individually examined on high altitude photography and digitized using the interactive Signal Processing System, discussed in Section 3.7 of this chapter. Once the original field is digitized, a healthy sample area within the same field is located. For this healthy sample area mean and standard deviation statistics of tonal values are calculated. These statistics are then expanded to the full field area (based upon the total number of digitized picture elements, i.e. pixels) using the normal probability density function:

$$Z = \frac{1}{\sigma \sqrt{2\pi}} e^{- (Y-\mu)^2 / 2 \sigma^2}$$

Where Z indicates the height of the ordinate of the curve, representing the frequency of the items.

Y = variable in question, in this case the optical density of the photograph.

μ = parametric mean of sample

σ = parametric standard deviation of sample

π = pi

e = base of Napierian logarithms

This function determines the frequency histogram of the sample healthy area. When multiplied by the number of pixels in the full field these frequency values generate the distribution that would be expected if the full field had the statistical characteristics of the healthy sample. An assumption is made that a healthy field or sample area will have a fairly normal distribution of tonal values. This assumption is strongly supported by our preliminary analyses. Once the expected healthy distribution of tonal values is obtained these values are subtracted from the actual field tonal values and the absolute values of the difference are summed. This assures that positive and negative differences do not cancel out one another, which would otherwise result in a summation value of zero. Division

¹ From Biometry, by R. Sokal and F. Rohlf, W. H. Freeman and Company, 1969.

of this difference value by 2X the total number of pixels results in a value that will range from 0 to 1.0 depending upon the similarity of the healthy sample to the total field. A value of 0 would imply totally similar statistics while a value of 1.0 means no overlap in the range of values. For convenience, these values can also be converted into percentages (0-100%) and termed the "deviation from normal field densities." Analysis of 13 intensively sampled fields has resulted in a very encouraging positive correlation ($r = .79$) between the average field salinity value and the "deviation from normal field density" value.

Most likely the weakest aspect of the soil sampling prediction procedure will be for fields that do not possess any visible damage. In this case the only assumption that can presently be made is that the soil salinity of the field is \leq the 0% threshold salinity value for that particular crop. Possible alternatives to this assumption, based upon average salinity values for each crop or soil type, are currently being investigated.

The predictive model as outlined thus far has been concerned only with the analysis of soil salinity based on an examination of a single date of imagery. The use of multirate imagery for crop damage mapping was primarily to assure the presence of crop cover on at least one date. By using a multirate image analysis approach it is also believed that the predictive methodology will be able to effectively "bracket in" the soil salinity of a field by analyzing the crops planted and the damage present as a function of time. In this manner variations in soil salinity in a region might be identified long before detection by field point sampling. If the interpreter consistently begins to identify more salt tolerant crops (cotton, etc.) being planted in an area and consistently notes that damage is increasing for the less tolerant crops (beans, etc.) such observations are very likely reflecting a gradual change in soil salinity. The reverse can be stated as well in terms of a greater percentage of non-tolerant crops with less visual damage reflecting a decrease in soil salinity. GRSU is continuing to conduct research into this area and will report the progress in future Grant reports.

3.60 PERCHED WATER

3.61 Introduction

The southern portion of the San Joaquin Valley, California is a basin of interior drainage. The addition of major inputs of exogenous water without adequate provision for its disposal has created a number of problems within our study area. This is especially true in the areas of ancient drainage channels where interbedded sedimentary deposits, some containing impermeable layers of clay,

have led to the development of a series of perches of the area's groundwater table.

KCWA has recently completed a major phase of its brackish water investigation in Kern County. A shallow hole drilling program was carried out utilizing a power auger to drill 152 holes (10" diameter) to depths of twenty feet. The investigation was designed by KCWA to identify "perched" water accumulations within 10 feet of the surface. The investigation indicated that an area of about 37,000 acres fell within this category, an increase of approximately 35,000 acres since 1963. Within this same area, water was encountered at depths of less than five feet on nearly 7,000 acres of land. In 1963, only 120 acres were in this condition. It is anticipated by KCWA that in the immediate future drainage problems will continue to develop within that area identified as having brackish water within twenty feet of the ground surface (74,000 acres). Earliest problems can be expected within the zones where the depth of water is now ten feet or less (37,000 acres).

The area covered by this survey included the Kern River flood channel, Goose Lake Bed, and adjacent areas between Buena Vista Lake Bed and Kern Wildlife Refuge. All of these areas have been identified as being potential perched water areas by GRSU research.¹ GRSU research on remote sensing techniques for the identification of perched water was delayed until the substantial drilling program undertaken by KCWA could be completed. This study provides an accurate ground truth data base for our analyses. Basically, our initial delineation of suspected perched water areas was accomplished using one date of highflight photography.² A major difficulty encountered in this initial phase of our investigation was related to the task of differentiating between soil types and existent soil moisture regimes using imagery from only a single date.

3.62 Goal

Our basic goal in this phase of our research into the application of remotely sensed data to the determination of water demand information is to ascertain the ability of remote sensing techniques and methodology to supply information related to areas of potential groundwater problems. In the case of Kern County the identification of those areas where the greatest potential danger of groundwater creating a hazard to the growth of crops exists is of major concern.

¹ Michael R. Rector, Brackish Water Investigation Shallow Water Table Survey, Kern County Water Agency, Bakersfield, 1974.

² Included in the Santa Barbara Section of the May, 1974 NASA Grant Report.

3.63 Methodology

As previously mentioned, one attempt at mapping suspected perched water areas has already been accomplished using a single date of highflight photography and manual photointerpretation techniques. This map was generated without the aid of collateral field verification data concerning the specific areas under investigation. In this study the major basis for the interpreter's decision as to whether or not a perched water table existed in a given region was a high correlation between dark soil signature on the CIR highflight photography and perched water in a similar, previously sampled region (Buena Vista and Kern Dry Lakes). As reported, it was considered unlikely that accurate distinctions were being made by our interpreters between different soil types as opposed to differing soil moisture regimes within an individual soil type. In addition, it was found that saline deposits confused the interpretation process by providing an overriding light tone signature even when soil moisture was high.

These difficulties, however, should be considered in light of both the original purpose of the first map and the time and image constraints under which it was produced. This map was originally intended to provide a guide for the KCWA well sampling program. A comparison of this map and actual well sampled perched water levels are included in the results section of this discussion.

3.64 Results

In many ways these initial results, detailed in Table 3-14, were encouraging for such a preliminary effort. However, both from an intuitive as well as a practical interpretative viewpoint the problems encountered suggest the exploration of alternative methodologies to the single date CIR photointerpretation approach.

One alternative currently being investigated is the use of multirate/spectral LANDSAT imagery. Initial analyses of band ratioed LANDSAT computer compatible tapes have shown interesting results that might be effectively utilized for predicting soil moisture in areas where bare soil conditions prevail. The presence of any crop cover, however, complicates this technique. Unfortunately, perched water tables are severest (that is groundwater is found closest to the surface) during the height of the irrigation season. This is also the time when crop cover is approaching its maximum. While these LANDSAT efforts continue we are also exploring the use of thermal infrared imagery. Such imagery may be able to effectively overcome the effects of crop canopies. A flight is currently being planned that will attempt to make optimum use of diurnal temperature variations between perched and non-perched water table areas. KCWA personnel have

TABLE 3-14

PERCHED WATER MAPPING PROJECT:
INITIAL RESULTS OF PHASE II STUDY REGION
(Approximately 200,000 acres)

Percentage of area field identified as having perched water with respect to Geography Remote Sensing Unit mapped drainage problem areas.		
Contours (feet to perched water)	% In	% Out
<5'	62	39
5-10'	83	17
10-20'	41	59
<20'	56	44

Percentage of Geography Remote Sensing Unit mapped drainage problem areas with respect to areas field identified as having perched water.
43% of GRSU mapped area was perched water
57% of GRSU mapped area was not perched water

offered assistance to GRSU in this effort by integrating a new well sampling program with the flight. These data would provide an accurate ground truth data base that interpreters can attempt to correlate with the tone signatures apparent on the thermal infrared imagery. Buena Vista and Kern Dry Lakes region tentatively have been chosen as the primary study site for this flight test program owing to the uniformity of soils throughout a large portion of the area. A secondary test site in the east side of the San Joaquin Valley is also being considered to examine a similar problem, in a slightly different environmental context, involving the water-logging of citrus orchards. This portion of our research is being proposed in conjunction with the Soil Conservation Service of the United States Department of Agriculture as a Special Study and will be briefly discussed again in that section of this chapter covering such studies.

3.70 IMAGE PROCESSING

During this reporting period GRSU personnel visited both the Remote Sensing Research Program (RSRP) and University of California Berkeley Radiation Laboratory Computing Facility to further explore the installation of a remote terminal at the University of California at Santa Barbara (UCSB). This terminal will have access to the CALSCAN set of pattern recognition programs developed by RSRP. Such an installation will greatly increase the integrated nature of our water resources research. By utilizing the facilities of the UCSB Computer Systems Laboratory (CSL) and the University of California's private intercampus telephone network an operations configuration has been developed that will emulate a remote terminal at no hardware expense. The required software for initiating this link is currently being developed with preliminary data transfers planned for by June of this year.

Due to the moderate quality of the telephone link (in terms of data transfer rate) this terminal will have limited image transferral capabilities. This handicap will be eliminated upon the successful connection of the UCB Radiation Laboratory to ARPANET. The CSL is already connected to the NET, being one of the original four "cornerstone" sites. The Radiation Laboratory is tentatively planned to become fully operational as a host site on the NET this coming summer. In its present configuration our link to the Radiation Laboratory will primarily be used to transfer class training set data to Berkeley for analysis by CALSCAN. This analysis will generate coefficients that can then be utilized to classify full scene imagery either at the UCSB Computer Center or, after transferring a digital tape to Berkeley, the UC Radiation Laboratory Facility.

¹ Advanced Research Projects Agency Network

As already mentioned, the UCSB Geography Department's image analyzer is currently being integrated into the CSL's Interactive Signal Processing System, thereby greatly increasing the GRSU's image processing capabilities. The Central processor of this system is an SEL 810B mini-computer with many peripheral devices, including a card reader and punch, teletype, 2 disc drives, storage drum, and various graphics displays. Of special interest to image processing is the UCSB On-Line System (Culler-Fried System), an interactive graphics display system developed by CSL to pursue problems in the physical sciences. This algebraically oriented language provides the basis for the CSL Interactive Signal Processing System and creates a highly interactive atmosphere with a graphics display suitable for many types of image processing research. The quantitative assessment of salinity damage, discussed earlier in this chapter is the first task for which the GRSU has utilized this system. Future reports will no doubt detail many other applications.

3.80 FUTURE WORK

GRSU research during this reporting period has concentrated on the water demand aspects of the integrated study. Proposed future work will generally follow this same emphasis with a continued major portion of our research directed toward the KCWA hydrology model. Expansion and partial completion of our five primary model-related research topics is anticipated in the coming fiscal year. The study topics, as detailed in this report, are:

1. Cropland Mapping
2. Crop Identification
3. Water Demand Prediction
4. Salinity
5. Perched Water

The determination of parameters that are critical to agriculturally oriented water demand models is essentially complete (see Work Item 1, Figure 3-2). Remote sensing techniques have been evaluated for most of the major model inputs that originally appeared amenable to such methods (Work Item 4). Specific procedures are still being refined in this phase of our research. Parallel to this, conventional methods are being investigated (Work Item 5) to facilitate cost-effective comparisons with remote sensing techniques (Work Item 6).

The analysis of economic impacts resulting from changes in water demand information (Work Item 2) and the effects of changes in the estimation of critical parameters (Work Item 3) have been difficult to determine. Basically, this results from difficulties involved in generating a conventionally gathered data base, separate from a remote sensing augmented data base. Once the two data bases are generated, the independent operation of the model for each

separate data set should provide results that can be directly correlated with each data source. As operation of the model is costly, this approach will require detailed preparation which, though already underway, may not be completed during the next reporting period. Only when such an analysis is complete can overall estimates of the potential impact of using remote sensing techniques in water demand problems (Work Item 7) be made with confidence.

In addition to GRSU water demand studies, several special studies are being proposed. The first three are directly related to water resource management (though not specifically water demand) and hence directly aid the overall integrated study. A brief description of each proposal follows.

3.90 SPECIAL STUDIES

3.91 Cropland Mapping and Crop Identification Techniques in Coastal Environments

This study is being proposed in conjunction with the Santa Barbara County Water Agency and the University of California Extension Office of Santa Barbara to evaluate coastal croplands and crop identification techniques. A large portion of the present GRSU study region falls within an arid environment in which the application of irrigation water creates a primary component of groundwater dynamics. Accordingly, most of our efforts have been directed toward the development of techniques and methodologies to inventory and monitor agricultural activities from which estimates of water demand can be derived. The uniqueness of the arid environment (Kern County) for which these remote sensing techniques have been developed, however, raises many questions concerning their transferability to other dissimilar regions. Santa Barbara County is considered a region directly accessible yet dissimilar enough to Kern County to allow assessment of technique transferability. Specific research topics to be examined are:

- 1) The effects of small irregular fields upon croplands mapping and crop identification from satellite imagery.
- 2) The feasibility of distinguishing between irrigated and non-irrigated croplands.
- 3) The impact of a different climatic region, especially increased cloud cover, upon crop identification techniques.

The first stage of this research will concern croplands mapping, i.e., no species differentiation will be considered except for a possible irrigated/non-irrigated distinction. Mapping will be from May, 1975 1:32,000 and 1:125,000 CIR high altitude (65,000 ft.) photography and 1:1,000,000 LANDSAT multispectral, multirate satellite imagery. Interpreted data will be transferred optically from the

photographs and imagery to USGS 1:24,000 topographic quadrangle sheets. These quad sheets provide a geometrically accurate base from which areal information can be obtained. A major function of our research is to encourage the transfer of beneficial remote sensing techniques; therefore an accurate record will be kept of the accuracies, time, and costs of all techniques utilized.

The second stage of our research will be directed toward the applicability to Santa Barbara County of crop identification techniques utilizing LANDSAT imagery. The synoptic (109 nmi X 109 nmi) and temporal (every 9 days) coverage of LANDSAT-1 and 2 should prove most beneficial to this portion of the study. If it is not possible in the first stage of the research to distinguish between irrigated and non-irrigated croplands such a distinction, as well as the croplands inventory itself, should become a by-product of the crop identification study. It is within the confines of crop identification that the effects of small irregular fields and cloud cover become of interest. This stage of the study will also incorporate a thorough cost-benefit analysis of techniques explored.

In order to accurately assess crop identification accuracies it will be imperative that reliable field verified data be generated. Accordingly, the Santa Barbara County Water Agency is funding the GRSU to undertake a countywide field verification program of agricultural croplands.

Information generated by this special study will be available to all interested agencies at the local level and it is anticipated that extensive cooperation between these agencies and the GRSU will be necessary to assure the success of the final product: a methodology for cost-effectively crop mapping Santa Barbara County from satellite imagery. If successful, this methodology will be incorporated at the local governmental level.

3.92 Groundbasin Permeability Study

This special study is proposed in conjunction with the Santa Barbara County Office of Environmental Quality. The purpose is to determine the usefulness of remote sensing techniques for measuring the relative proportion of permeable vs. impermeable surfaces overlaying groundwater basin recharge areas. GRSU personnel have recently been involved in a survey that utilized low altitude photography (scale 1:10,000) and the manual delineation of permeable and impermeable surfaces. This initial survey resulted in an intricate thematic map of permeability for over 6,000 acres. The detail of this map made manual planimetry impractical from both time and monetary constraints. The Geography Department's image analyzer was effectively used to density slice the overlay and electronically planimeter the

various classes. The expansion of this technique for the delineation and mensuration of color-keyed thematic maps, through pattern recognition procedures, is anticipated in the near future. The initial data generated by this project will provide accurate "ground truth" for use in analyzing remote sensing techniques based on highflight color infrared photography and a pattern recognition analysis.

3.93 Detection of Waterlogged Soils

This study is proposed in conjunction with the Soil Conservation Service of the Department of Agriculture to evaluate the use of remote sensing techniques to detect and delineate waterlogged soils in the east side of the San Joaquin Valley, mainly in citrus orchards. The study would benefit as well as aid the GRSU research into perched water detection and if successful would be especially useful to the SCS in their upcoming analysis of the San Joaquin Delta region.

As discussed earlier in the "Perched Water" section of this chapter, a thermal infrared flight is tentatively being planned for inclusion in this analysis.

3.94 Oil Field Sump and Road Mapping

This project is proposed in conjunction with the Division of Oil and Gas of the California State Resources Agency. Recent legislation has required the covering of all open oil field sumps and the enforcement of construction safety regulations. The GRSU has previously been involved with the Division of Oil and Gas in a mapping project where all discernible sumps were mapped from 1:60,000 color infrared highflight photography onto 7 1/2 minute quadrangles. These sheets were then distributed to personnel of the Division of Oil and Gas and of the Department of Fish and Game so that each sump could be field checked and its condition noted. (One lesson learned from field checking was that a large percentage of time spent in the field could have been eliminated by the availability of more recent maps. It was also found that oil sump detection could be improved by the use of more nearly optimum film/filter combinations and better resolution imagery.) The region involved in this study would be the five coastal counties from Monterey on the north, to Orange County on the south.

The Division of Oil and Gas has also expressed interest in the development of a procedure to map offshore oil seeps in the Santa Barbara Channel. The Division is currently awaiting the results of a GRSU feasibility study for oil seep mapping before reaching a decision as to which project to support with matching funds.

3.95 Forest Fire/Fuel Study

This special study is proposed in conjunction with the CRSR and discussed more fully in their section of this report.

CHAPTER 4

USE OF REMOTE SENSING TO DETERMINE THE WATER DEMANDS OF THE UPPER SANTA ANA RIVER DRAINAGE BASIN

Co-Investigator: Leonard W. Bowden, Riverside Campus

Contributors: C. Johnson, D. Nichols, J. Drake,
G. Thomas, A. Van Curen, E. Harnden,
G. Washburn

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Chapter 4
Table of Contents

4.1	Introduction	4-1
4.1.1	Objective	4-1
4.1.2	Location and Physical Factors	4-1
4.1.3	Water Rights and Historical Demand	4-4
4.2	Public Agencies' Cooperation and Preliminary Cost Benefit Estimates	4-5
4.3	Current Studies	4-6
4.3.1	Machine Assisted Santa Ana Basin Land Use Mapping	4-7
4.3.2	Estimation of Water Demand Factors	4-18
4.3.3	Special Investigations of Agricultural Land Use	4-34
4.3.4	Monitoring the Water Disposal of the Chino Valley Dairies	4-34
4.4	Future Studies	4-39
4.4.1	Water Demand Studies	
4.4.2	Remote Sensing Studies of the Southern California Coastal Environment	4-42

Chapter 4.

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4.1 Introduction

The use of high altitude remotely sense imagery to determine long-term water demand through analysis of land use is proving to be most effective. The California State Department of Water Resources (DWR) has, for many years, forecasted long-term water demand by an empirical model that utilizes net land use as the driving parameter. Our results seem to bear out that we have improved the model in both accuracy and the rapidity with which forecasts of water demand can be obtained.

4.1.1 Objective

The objective of the current investigation has been to obtain the most accurate up-to-date land use determination in the Upper Santa Ana River Drainage Basin of southern California by the least expensive methods in order to determine water demand. Remote sensing has long been employed to determine land use, but generally only by means of low level aircraft flights. Preliminary findings show that a single high-altitude (NASA U-2) image can replace many low altitude images and yield far less distortion while permitting much faster data reduction to determine water demand in the Upper Santa Ana Drainage Basin.

4.1.2 Location and Physical Factors

The upper Santa Ana River Drainage Basin lies east of Los Angeles (Figures 4-1 and 4-2) and is separated from the coastal Los Angeles Basin by the northern extent of the Santa Ana Mountains and by the Chino-San Jose Hills which rise to the west of the Elsinore Fault zone. The only river outlet of the basin is the Santa Ana River which flows through the gap separating the Santa Ana Mountains from the Chino Hills. The Elsinore Fault cuts across the upstream entrance of Santa Ana Canyon with the west side of the fault block rising nearly to the surface where it forms a barrier to underground water flow. Thus all underground water is stored or flows to the surface. At this site the Corp of Engineers has built the Prado Flood Control Dam which permits only regulated surface water to continue downstream to Orange County. At the southern end of the upper Santa Ana River Basin, between the Elsinore trough on the west and the San Jacinto Fault on the east, lies the Perris fault which effectively block the drainage of any surface water to the south. The north and east sides of the basin are divided into the San Gabriel, San Bernadino, San Jacinto, and Santa Rosa Mountain watersheds. The mean annual rainfall increases from 28 cm (11 inches) in the southwest portion of the basin to over 38 cm

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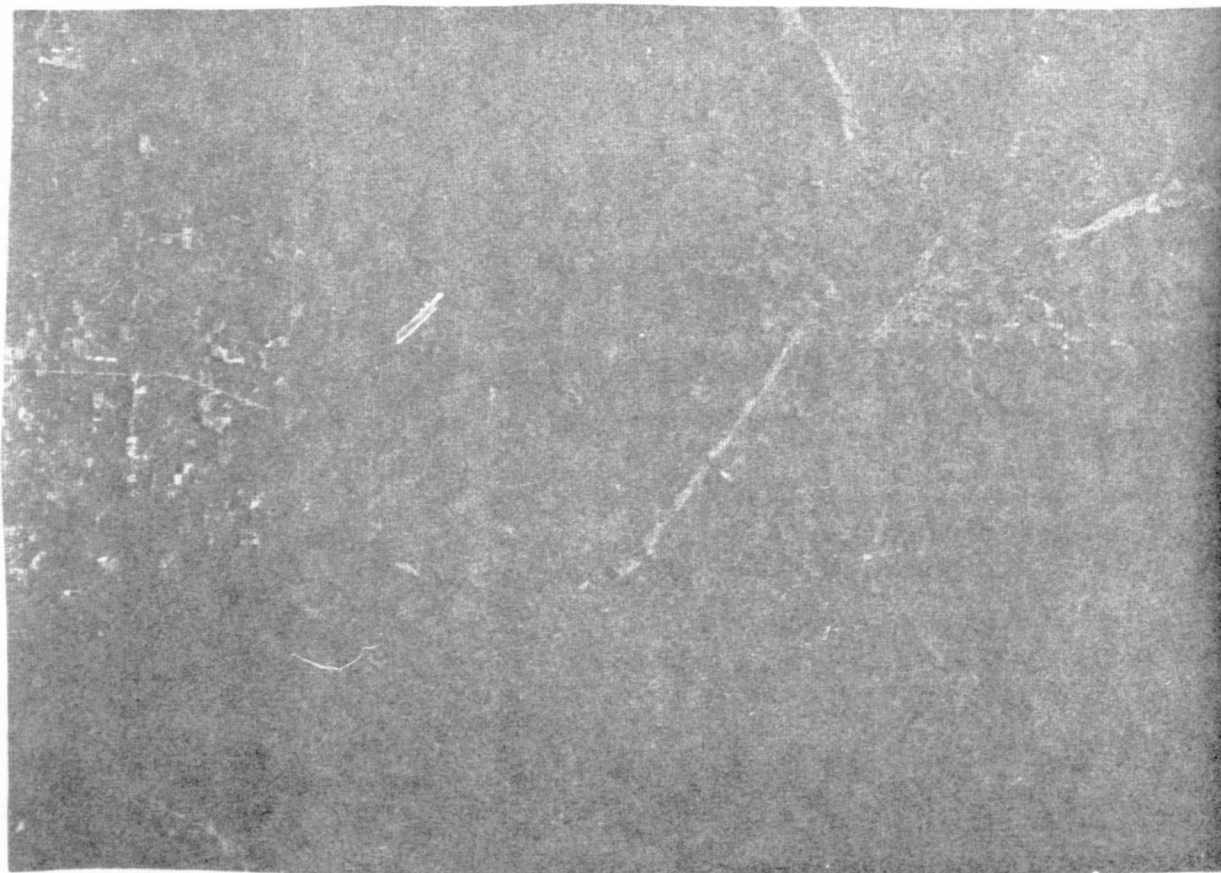


Figure 4-1. Color infrared (CIR) photo mosaic of the upper Santa Ana River Drainage Basin
(NASA-Ames U-2 photo 11 July 1972. Nominal scale of original photo 1:130,000
Scale of this photo 1:660,000)

4-3

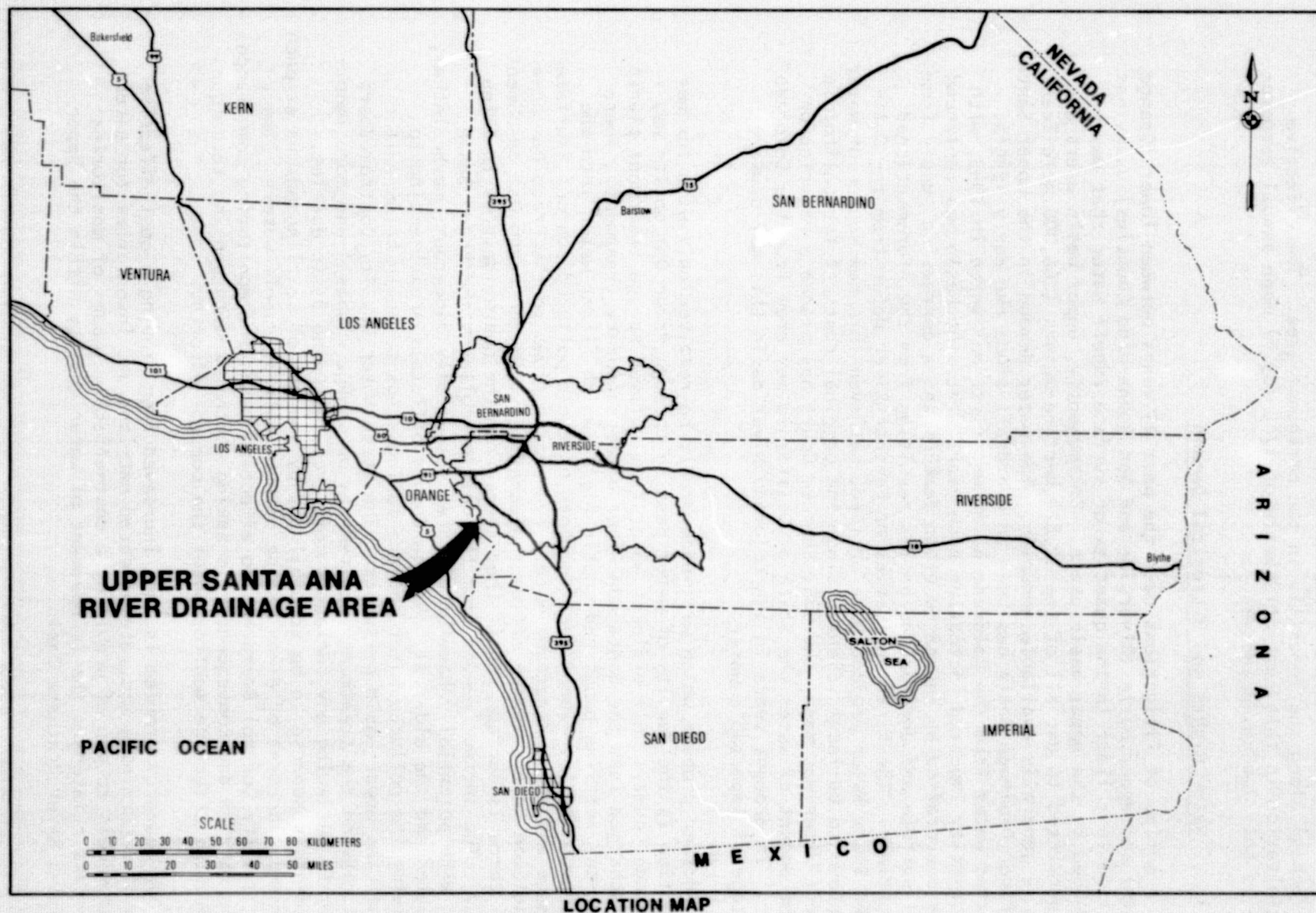


Figure 4.2 Location Map of Upper Santa Ana River Drainage Basin

(15 inches) along the foothills in the northeast area. The effective precipitation in this semi-arid basin of 17°C (63°F) mean annual temperature is only 7.6 cm (3 inches).

4.1.3 Water Rights and Historical Demand

A series of litigations over the past 25 years between lower (Orange County) and upper basin (Riverside and San Bernardino Counties) users has resulted in a limit in the quantity of surface runoff water that may be impounded by the upper basin users. Consequently, upper basin users are not permitted to use all of the 32,824 hectare-meters (266,000 acre-feet) that is generally available annually. The water demand in the Upper Santa Ana River Drainage Basin has been an overdraft since the early 1940's. Imported water from the Colorado River was first delivered in 1943, with the quantity imported increasing each year. Yet, the basin has continued to be overdrafted by increased urban demands and a decreasing supply from local surface and underground basins resulting from the aforementioned litigations. The first deliveries of Feather River Water from the California State Water project have arrived, but even this new source of water may prove to be insufficient. Since the original contract for California Project Water was made, the U.S. Supreme Court has placed a restriction on the amount of water the State of California may draw from the Colorado River. In drought years in the Colorado River Basin this may cause a shortage of importable water.

Another problem which will undoubtedly be resolved only with further litigation is the quality of water passing through Prado Dam on its way to Orange County. All effluent water from upriver sewage treatment plants is discharged into the Santa Ana River after secondary treatment. There exist many settling ponds and septic fields which filter water into the underground basin. The water from both of these polluted sources (surface drainage and the underground water) eventually flows to the Prado Dam area. In addition to the sewage effluent discharging into the Prado Dam catchment basin there is surface runoff that comes from the nearby dairies in Chino Valley. The surface runoff from the dairies pollutes the Prado Basin water with potentially harmful nitrates (especially dangerous, maybe lethal, to babies and the elderly). Orange County officials are objecting to receiving the polluted water and are taking steps to again bring suit against the upper basin polluters. The State Water Quality Control Board is increasing the treatment requirements on sewage disposal and more importantly is outlawing any surface runoff from the Chino Basin dairies. Treatment is suppose to be accomplished by the use of settling basins at each dairy and placement of dikes in the path of natural runoff waters. The Water Quality Control Board has no effective means for monitoring compliance by the dairies and consequently is asking whether remote sensing techniques can provide effective monitoring of the control efforts.

Our research problem is thus increased from finding a cost-effective means of determining accurate up-dated net-land use inventories for eater demand models to one of providing a cost-effective means of monitoring parameters related to the improvement of water quality within the Upper Santa Ana River Drainage Basin.

4.2 Public Agencies' Cooperation and Preliminary Cost Benefit Estimates

During the past year cooperation with public agencies has increased significantly. Because of the heavy emphasis on water demand in these studies it has only been natural that the public agency of prime concern be the State Department of Water Resources (DWR). However, the study has generated considerable interest from the Santa Ana Region State Water Quality Control Board as well as the planning departments of the two concerned counties, Riverside and San Bernardino.

Robert Smith, who is Senior Water and Land Use Analyst, Southern District (Los Angeles), DWR, has been in weekly contact with our research group, exchanging ideas on improved methodologies and stating specific areas of interest or concern to the department. To assist DWR with updating its land use files of the Upper Santa Ana River Drainage Basin all land use interpretation data accomplished by UCR has been duplicated for the DWR. Analysts from the DWR have come to Riverside and we have cooperated in reevaluating specific areas of question and concern. As noted elsewhere in this report, the two different land use codes (UCR and DWR) have been cross-related to enable conversion from one file to the other. This past year's cooperative efforts with DWR were culminated on April 9, 1975 with a half-day symposium given for 21 Senior Water and Land Use Analysts from all of the various districts and state headquarters of the State Department of Water Resources. Emphasis was on the procedures developed to provide machine-assisted land use data conversion and analysis. The current development of a machine overlay system to permit updating and correlation of the data with specific municipal water districts was evaluated and considered most desirable.

Discussions of the costs and benefits of the machine oriented systems being developed were not conclusive, but generally indicated the following:

1. Initial map preparation and conversion to machine code requires about the same number of man-hours as required for complete manual processing.
2. Cost-benefit ratios begin to improve significantly when, once in machine form, the data are: a) analyzed; b) crosscorrelated with other data; c) used to produce statistics such as acreages or population densities, and/or; d) used to produce maps with various scales and shadings.
3. Cost-benefit ratios will be greatly improved when updating procedures are performed. Preliminary studies indicate that approximately 20 man-hours will provide machine input data for a map update where normal manual updating procedures may require upwards of 200 hours. For this one study area alone such savings would apply to 30 maps.
4. Great interest was shown by the DWR analysts, not only in studying the machine assisted processes, but in determining the relative costs for the hardware required to place each district into operation on a machine assisted basis. (It was agreed that the minimum starting cost for hardware was only \$15,000.)

Gordon Anderson, of the Santa Ana Regional Water Quality Control Board, has been most concerned with assistance to the Dairy farmers in the Chino Valley area of the Basin. As enumerated in the current studies section of this report the concern is with the pollution of surface waters from the wash-down and rain run-off waters. However, of considerable concern is the pollution of the ground waters resulting from the spreading of wash-down water. The November 26, 1974 flight with the HR-732 camera of the NASA-Ames U-2 aircraft resulted in excellent imagery for spotting the effectiveness of ponds and dikes to retain run-off waters as well as showing areas of needed improvement.

Jack Newcombe, Planning Director, Riverside County and his associates have been most concerned with the development of machine assisted techniques. In addition to cooperating in the land use mapping they are in the process of adopting a machine assisted land use system. The actual development of their system will be through a cooperative effort with Southern California Edison and Environmental Systems Research Institute (ESRI) of Redlands. The latter group has worked closely with use in developing machine processing techniques.

Ken Topping, the planning Director of San Bernardino County, and his associates have also been in consultation on a periodic basis. The county has completed the acquisition of a machine assisted land use mapping system also in cooperation with Southern California Edison and ESRI. Ron Matyas, a former employee on this project at UCR, was hired to supervise the implementation and operation of machine assisted operations in the S.B. County Planning Department.

In anticipation of future studies along the southern California coastline we have been in contact with Dan Davis, Special Consultant, to the California Coastal Zone Conservation Commission. He is most concerned with coordinating efforts directed toward making a remote sensing analysis of the coastline. He has requested that we cooperate in a study of coastal marshlands, which study would also involve the State Fish and Games Commission. The current target of primary concern is the Oxnard Plain. As listed in the proposed future studies section of both this report and the December 1974 semi-annual report we have proposed to study all of the marsh land areas of the southern California coastline.

Tad Widby, transportation planner, Southern California Association of Governments (SCAG), has consulted with us and stated that one of SCAG's concerns is not more data, but an organization of the current coastline data the better to apply such data to transportation studies. Included with this organization of data (i.e. a Coastal Information System) is the provision for establishing a common time base for all data.

4.3 Current Studies

The development of a Water Demand Model for the Upper Santa Ana River Drainage Basin has led to four related studies. First it is necessary to identify the land use of the basin because land use is the determinant

(driving) parameter in the water demand estimation model. The second study seeks to relate water use to land use. Utilizing the data provided from the first study required that all land use of the same classification be assigned a value which accomplishes a reduction to net water use areas. That is, all non-permeable areas contained within a specific land use type must be deducted from the total (gross) area. The accuracy of the DWR's current Net Reduction Land Use Factor thus becomes a prime concern. However, the DWR as of 1975, has committed itself to an estimation procedure for non-agricultural water use in selected service districts based on a weighted per capita factor for urban areas. This method appears to be more promising than the one formerly used and it appears that remote sensing can be utilized in conjunction with census data to provide very accurate estimates of the population parameters needed to derive the urban per capita factor. A third study, specifically requested by the DWR, is designed to determine the number of months each year during which various types of agricultural fields lay inactive and hence do not need irrigation. Agricultural water demand estimates made by the DWR are made with only a fair guess as to the duration of the inactive season. Because agriculture represents 33% of the land use in the basin, the accuracy of determining the inactive season can make a considerable difference in the overall water demand estimate. A fourth study is concerned with determining the quality of recycled water within the basin. A large concentration of dairies (displaced from Los Angeles and Orange County) exists in the Chino Valley area of the basin. Disposal of both the solid waste and waste water (including 47 gallons daily wash down water per cow) containing highly concentrated nitrates is of concern. The Santa Ana regional office of the California Water Quality Control Board has requested that we include in our project a feasibility study on the use of high altitude aircraft imagery to monitor the control of waste material and water from the dairy industry.

4.3.1 Machine Assisted Santa Ana Basin Land Use Mapping

The development and maintenance of a water demand model requires both current and accurate data for the driving parameter. The State Department of Water Resources has determined that the most reliable parameters are land use and population. Changes in long-term living habits are expressed visually in a change of land use. These changes are most accessible through the use of aerial photography and thus provide a unique opportunity for NASA test platforms to display their ability to provide data for solving long-term water resource problems.

4.3.1.1 Philosophy of Approach

Current staffing and equipment at the Department of Water Resources (DWR) permit the inventory of a region only once every decade. With the fast change in land use from rural to urban in many areas of California the DWR is forced to make long-term water demand forecasts with outdated and perhaps inaccurate data. A system is needed that will provide accurate and easily updated land use information. Any system developed must be economical and attainable within the low budget of the various district offices. A statewide computer system is available to the various offices if they can prepare the

data within the capabilities of the local district. The present state of data reduction within district offices is exemplified by the fact that acreage calculations currently are being accomplished by a careful cutting out of each field as portrayed on special prints of land use maps and by weighing the resulting pieces of paper. Hence, exotic systems that employ procedures of discriminant analysis to identify land use cannot be feasibly transferred to state use at this time. The adoption of a system of machine assisted land use inventory would be pushing the financial limits of the local office, but nevertheless could be accomplished if a significant improvement in terms of cost/benefit ratios could result therefrom. With cooperation from the Los Angeles District office of the DWR the machine assisted land use system described below is being developed, utilizing high altitude aircraft (U-2) imagery for data.

4.3.1.2 Analysis of Imagery and Land Use Classification

Five seasonal high altitude aircraft (NASA U-2) missions have been flown of the basin (December 10, 1973, March 14, 1974, June 3, 1974, October 16, 1974, and November 26, 1974). The first four flights employed the RC-10 camera system with the 153 mm (6 inch) lens and color infrared film (CIR). The 70 mm Vinton Camera package provided the secondary sensor system. The November flight was made up of an RC-10 camera and an HR-732 camera, both containing CIR film. The RC-10 camera used the regular 153 mm (6 inches) lens and the other camera used a 610 mm (24 inches) focal length lens.

The 1:130,000 scale CIR imagery is providing an average ground resolution of about 6 meters (20 feet). The 1:32,500 scale imagery is providing around resolution of about 1.3 meters (5 feet). This is proving sufficient to interpret land uses to better than the second level of classification (see Table 4.1) which is adequate to fulfill the need to determine water use categories. Once the photo interpreters have been given a few hours of special interpretation training, they can identify virtually all dairies from the imagery to include differentiation between corrals, milksheds, residence houses, and the definition of pasture boundaries.

Our research effort has contributed to a further understanding and definition of land use classification systems from high altitude and satellite imagery. The land use definition required for calculating water demand differs from that needed by most planners. Planners desire more detailed urban identification while water resources agencies are more concerned with unit area definition. The ideal classification system would provide sufficient definition in both urban and rural environments for all users. Therefore, the studies performed under this grant have been to develop a system that would provide the most accurate water demand estimate, but at the same time could be used in a machine assisted geographic information system capable of being utilized by other types of users without modification. Table 4.1 lists the UCR land use classification adapted to this study with the equivalent State Department of Water Resources land and water use classification shown in the adjacent column.

Table 4.1

LAND AND WATER USE CLASSIFICATIONS

UCR CLASSIFICATIONS

<u>Code</u>	<u>Title</u>
<u>1</u>	<u>LIVING AREA</u>
11	Medium Density Urban (Single)
12	High Density (Multiple Units)
14	High Density (Mobile Homes)
15	High Density (Transient Lodge)
13	Low Density (Urban Estates)
16	Low Density (Rural Dwelling)
17	Low Density (Recreation Unit)
<u>2-3</u>	<u>INDUSTRIAL (Manufacturing)</u>
21-27	Light Industry
28-34	Heavy Industry
<u>4</u>	<u>TRANSPORT & UTILITIES</u>
41	Railways & Rail Terminals
42	Motor Transport Facilities
43	Aircraft Facilities
44	Marine Craft Facilities
45	Highways and Roads
46	Automobile Parking
47	Communications
48	Utilities (water, gas, elec. sewer)
<u>5</u>	<u>COMMERCIAL (Trade)</u>
51	Wholesale Trade
52-58	Retail Trade
<u>6</u>	<u>SERVICES</u>
61-66	Commercial & Professional
67	Government
68	Education
69	Social

DWR EQUIVALENT CLASSIFICATIONS

<u>Code</u>	<u>Title</u>
	RESIDENTIAL (URBAN & RECREATIONAL)
UR	Urban Residential
UC 2/RR	Motels, Urban & Resort
UC 4	Urban Commercial (Apts & Barracks)
UR	Urban Residential
UC 4	Urban Commercial
UR	Urban Residential
RR	Recreation Residential
	<u>URBAN INDUSTRIAL</u>
UI 1	Manufacturing
UI 61-12	Sawmills, Oil, Paper, Meat, Steel, Food
UI 3	Storage & Distribution
UV 4	Urban Vacant, Paved
UV 4	Urban Vacant, Paved
UI 3	Storage & Distribution
UI 3	Storage & Distribution
	<u>URBAN COMMERCIAL</u>
UI 3	Storage & Distribution
UC 1	Misc. Establishments
UC 1	Misc. Establishments
UC 6	Schools
UC 5	Institutions

Table 4.1(Continued)

UCR CLASSIFICATIONS

<u>Code</u>	<u>Title</u>
<u>7</u>	<u>CULTURAL, ENTERTAINMENT, REC</u>
71	Cultural
72	Public Assemblies
73	Amusements
74	Recreational Activities
75	Resorts & Camps
76	Parks and Golf Courses
<u>8</u>	<u>RESOURCES</u>
81	Agriculture
81.4	Dairies
82	Agriculture Related
83	Forestry Activities
84	Fishing
85	Mining
<u>9</u>	<u>UNDEVELOPED</u>
91	Land
92	Forest
93	Water (Incl Dry Channels)

DWR EQUIVALENT CLASSIFICATIONS

<u>Code</u>	<u>Title</u>
UC 7	Auditoriums, Theaters, Churches
UC 7	Auditoriums, Theaters, Churches
UC 7	Buildings & Stands w/race tracks, etc.
UC 7	Football Stadiums, sports parks
RT	Camp & Trailer Sites, Recreational
P	Parks, Recreation
A	Agriculture
A	
S	Semi-Agriculture
UI 2	Extractive Industries
	<u>URBAN VACANT/NATIVE</u>
UV-1	Unpaved, Urban Vacant
NV	Native Vegetation
NR	Riparian Vegetation
NW	Water Surface

One of the more significant adjustments in land use interpretation from high altitude aircraft/satellite imagery is in the Living Area (Residential) category. As seen on this imagery, housing density is a more apparent residential feature than are single buildings. Consequently, the concept of classifying living areas into low, medium, or high density classifications is introduced. The low density category includes "urban residential lots" of 0.13 hectares (1/3 acre) or greater, "rural residential lots" of 0.2 hectares (1/2 acre) or larger, and "resort houses," consisting of mountain cabins, or other type second home recreation house. Medium density housing is comprised of the area generally classified as separated single family dwellings on lots of less than 0.13 hectares (1/3 acre). High density living area can often be detected as apartments of 3 or more household units, hotels, motels, and other buildings devoted to providing shelter for multiple residents.

Industrial areas are detectable as either heavy or light. Light industries are usually of lesser acreage and found in a particular portion of urban areas according to local zoning ordinances. Some "ground truth" is usually required if differentiation between light industry and commercial wholesale trade is required. The heavy industries (oil, steel, food processing) are detectable by their larger acreage and urban fringe location.

The transportation classification, because of linear features or large overall size, can be identified to the third and even fourth level of classification although only necessary to the second level for this study. Likewise utilities (power substations, water plants, sewer plants, and gas facilities) are detectable to the third level from high-altitude imagery.

Commercial wholesale and retail trade is generally limited in detection to the first level of identification. Depending on location in the urban area, wholesale trade is confused with either retail trade or light industry. Second level detection of commercial trade buildings is extremely difficult unless the trade possesses some unique feature or else the imagery provides more than 6 ground meters (20 feet) resolution.

The service classification is detectable by the distinctive features of government, educational, religious, and hospital buildings. The exceptions are business and professional services. Unless business services are uniquely located, it is difficult to distinguish them from retail trade.

Amusements and recreational activities can often be classified to the third level because of the large land area involved. Cultural buildings and public assemblies demand approximately the same water use and can be consolidated for investigation. Recreational parks, golf courses, and resorts require a similar quantity of water due to the large expanse of grass areas. They too have been consolidated, although coded separately.

Resources in the Upper Santa River Drainage basin are classified into three second level categories; Agriculture, Forestry activities, and Mining. For the first phase of study, agriculture is only being classified to the

second level. The high altitude aircraft imagery taken on sequential dates provides adequate data to identify agricultural crops to the fifth level if necessary. Because of the specific investigation mentioned earlier, all dairies are being identified separately from general agriculture.

Undeveloped land is being coded to second level classifications of open land, forest, and water. Dry water channels are classified under undeveloped water even though many of the dry channels only carry runoff flood waters or underground percolation.

The four date, high altitude aircraft CIR imagery, has been adequate to classify all of the land use in the Santa Ana River Drainage Basin to the second level, a level adequate for a water demand model using land use as the driving parameter. (Driving parameter is defined as the one factor in a model that, if incorrect or changed in character, will cause the greatest error or change in the final results produced by the model.)

4.3.1.3 Planimetric Boundary Transfer

The Upper Santa Ana River Drainage Basin comprises 585,382 hectares (1,446,510 acres). To manage the interpretation of such a large region, it has been divided into more than 30 grid units of approximately 15,985 hectares (39,500 acres). Figure 4.3 shows the grid overlay imposed on the Basin. As noted the grids are comprised of U.S.G.S. 7-1/2 minute topographic quad sheets at a scale of 1:24,000. Areas not covered by the grid overlay are largely comprised of undeveloped forest lands. The use of quad sheets provides a planimetric basemap to which the interpreted land use can be fitted for accurate planimetry.

To provide for the accurate transfer of data from the 1:130,000 scale imagery to the 1:24,000 scale base, an enlarging process has been instituted. The RC-10 metric camera on the U-2 platform at 65,000 feet provides an almost distortion free image, especially within the area close to the nadir. To insure that transfer is planimetrically correct, a mylar overlay with control features (roads, rivers, etc.) outlined on the overlay is used to receive the projected image of a K & E Kargl enlarging/reducing projector. Boundaries of the various detectable land uses are then drawn on the mylar control map overlay. It is best to view the image on a light table through a magnifying lens to interpret the land use type. The Kargl enlarger imagery, when projected through the matte finished mylar, degrades the resolution to an unacceptable level. This method of boundary transfer from image to map has proved far superior to other manual methods previously employed and has maintained the required boundary accuracies for calculating acreages of land use. However, a more economical machine process needs to be developed for this phase of data reduction.

4.3.1.4 Digital Encoding of Polygon Data

The reduction of map data to digital form for computer processing has been time consuming and error prone. The original program obtained to produce shaded choropleth maps required that each vertex (any change of direction

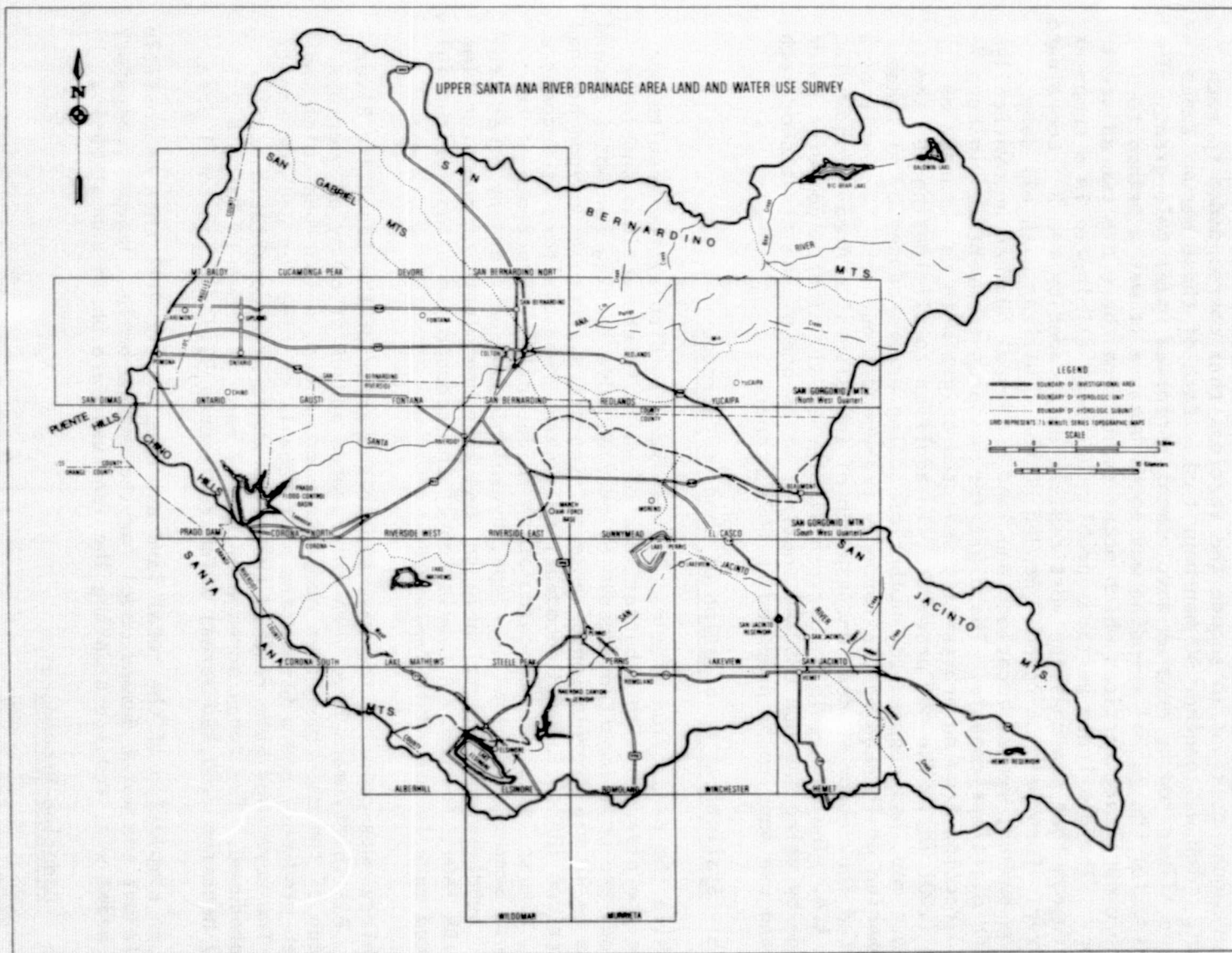


Figure 4.3 USGS 7-1/2' Grid Overlay of Upper Santa Ana River Drainage Basin for Land Use Interpretation

of a boundary) had to be hand numbered. Many of the quad sheets have well over 2,000 vertices which required up to 40 man-hours to hand number. Another manual task was to encode the vertices that corresponded to each polygon, which was another 40 man-hour task. Each of these manual tasks has been eliminated by program development performed under this grant. The reasoning for the manual encoding was sound because it was a method to eliminate duplicate vertices which occur every time there are two adjacent polygons. The duplicate vertices problem has been eliminated in a computer edit program that searches the vertices tables encoded by the X-Y coordinate digitizer. Each polygon is now encoded on the digitizer with all data (polygon number, vertex location, and land use type) punched automatically from the digitizer console. The digitizer measures the vertices in both X and Y direction from an arbitrarily selected origin with an accuracy of .25 mm (.001 in). The new procedure, in addition to eliminating 80 man-hours per map, has reduced the number of coding errors caused by mistakes in numbering or in reading the formerly pre-encoded numbers. A sample of a completed four-color shaded land use map of the Riverside Area is shown in Figure 4.4. The figure is a four pen simultaneously plotted computer color map made by using the UCR CHORMAP routine; it is one of the first choropleth type land use maps to be produced in this manner.

4.3.1.5 Statistical Compilation of Land Use Acreage

While the production of a map is necessary to display the results and provide the planners with a better idea of where future actions should be directed, the most important result of the land use mapping for water demand studies is in the compilation of acreage statistics. Once a polygon has had its vertices identified and encoded into machine readable form it becomes a simple, almost instantaneous calculation to determine the acreage of the polygon. Summaries by land use type, hydrologic sub-unit or any other pre-defined subdivision are obtainable in less than one minute of computer time on an IBM 360-50 system. A tabulation of the acreage summaries for the fully completed maps is listed in Table 4.2.

Thirty maps comprise the base map grid overlay of the Santa Ana River Basin. All thirty maps have been interpreted and exist on mylar overlays. Seventeen of the maps have been completely processed, a four pen color map has been produced, and a base scale plot tape is on file for each of the 17 maps. Two more maps have reached the stage where area compilations are being produced. The total acreage of the 17 maps as shown in Table 4.2 is 315,837 hectares (780,450 acres) which represents 53.8% of the total area.

Upon completion of the total land use mapping, it will then be possible to implement the water demand model for the entire basin. However, accuracy of the model will require updating the land use data on an annual basis.

4.3.1.6 Updating Procedures

In order to facilitate mapping land use change in the Upper Santa Ana Basin, objectives and procedures have been formulated. The objectives were devised to insure that: 1) current and reliable land use maps are produced

Table 4.2

PARTIAL LAND USE AREA OF THE UPPER SANTA ANA RIVER
DRAINAGE BASIN, 1975

<u>CLASSIFICATION</u>	<u>Hectares</u>	<u>Acres</u>
<u>LIVING AREA</u>		
Urban, Single dwelling	32,320	79,864
Urban, Multiple dwelling	896	2,215
Rural, Mixed dwellings	579	1,430
<u>INDUSTRIAL</u>		
Light	2,082	5,145
Heavy	1,325	3,274
<u>TRANSPORTATION & UTILITIES</u>		
Transportation	3,503	8,657
Utilities	1,496	3,697
<u>COMMERCIAL OR TRADE</u>		
Wholesale	68	168
Retail	2,610	6,449
<u>SERVICES</u>		
Business & Professional	332	821
Government	2,989	7,385
Educational	1,986	4,908
Social	43	106
<u>CULTURAL, AMUSEMENT & RECREATION</u>		
Cultural & Public Assembly	301	743
Recreational, Resort & Parks	2,713	6,703
<u>RESOURCES</u>		
Agricultural	69,402	171,495
Forestry, Fishing & Mining	685	1,693
<u>UNDEVELOPED</u>		
Land	58,486	144,522
Forest	126,636	312,925
Water (including Dry Channels)	7,386	18,250
TOTALS	315,837	780,450
Total Basin Acreage: 586,598 Hectares Percent Complete April 10, 1975 53.8%		
1,449,515 Acres		

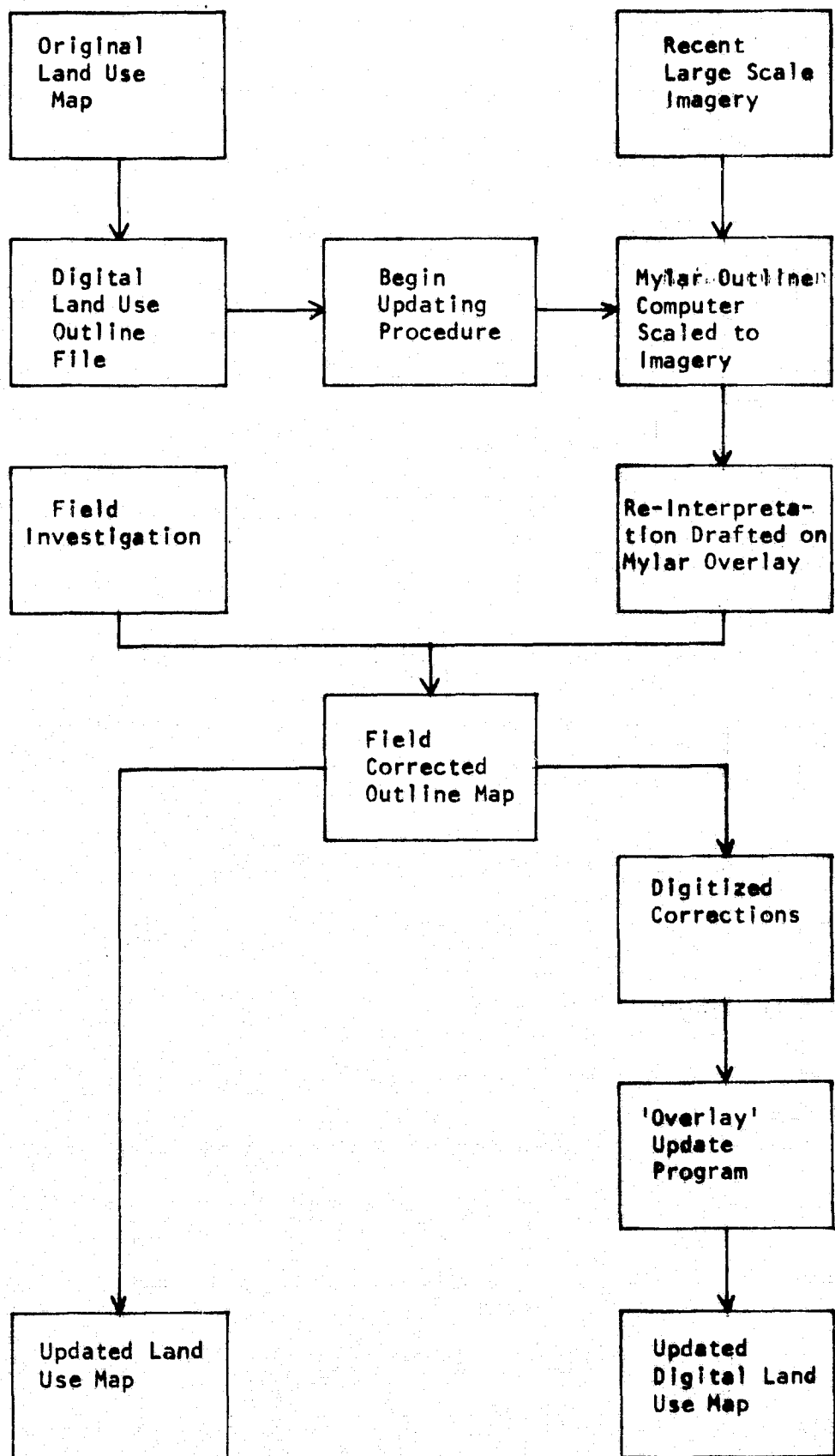


Figure 4.5.. Updating procedure flow chart

2) the land use succession can be detected and measured and; 3) the operational procedures and land use classification system are compatible with the land use information system.

The original land use map and the digital land use outline file are readily available for each quad sheet as a result of effort prior to updating. As recent imagery suitable for updating purposes is acquired, a mylar outline of the original land use is produced by the computer at the same scale as the imagery.

Land use change is compiled directly upon the mylar overlay which has the original survey plotted on it. The land use outline is then interpreted for change with the aid of a stereoscope (3x power). This procedure of drafting updated information upon the original map requires less production time and reduced the possibility of error during the transferring of data.

When changes need to be redrafted on the overlay, colored pencils are used so as to differentiate the type of changes and errors detected. The horizontal movement and the function change between the two time periods (4/30/71 to 11/26/74) are the primary points of interest.

The field investigation of the updated maps immediately follows the interpretation. Corrections of the map are made on the site location to reduce the error factor. An updated land use map is then produced from the field corrected map. The updating of the digital map file based on the changes detected by the above procedure is discussed under Section 4.4, Future Studies.

4.3.2 Estimation of Water Demand Factors

Two methods, requiring different data inputs, are currently being investigated for establishing estimations of water demand factors. The first method requires land use data, reduced to Net Water Service Areas by subtracting areas of non-water use from each distinct land use, based on land use type. The procedure for establishing this reduction from gross area to net area is discussed below. The second method relies on population data inputs and requires the assignment of a per capita water demand factor in order to estimate water demand for non-agricultural water users in selected DWR Service areas.

4.3.2.1 Factors for Reducing Gross Land Use to Net Water Service Areas

The California Department of Water Resources (DWR) utilizes a water consumption value based upon the Net Water Use Area. That is, it reduces gross land use areas to areas of permeable soils and building areas whose occupants consume water either in occupation or living. The continual change and regional variations in land use make it necessary to continually update the reduction factors for each region separately. The purpose of the following study was to develop a method of deriving net reduction factors using remote sensing techniques. It was discovered that the net reduction factors could be updated 125 times faster by remote sensing methods than

by conventional ground survey methods. An accuracy check indicated that land use classifications for this purpose as obtained by remote sensing techniques are within $\pm 5\%$ of actual ground measurements. The inherent error in estimating the overall water consumption per water use area makes the 5% variance insignificant, especially in view of the savings in time offered by the remote sensing method.

By DWR definition, the water service area is an area containing many non-water use areas which would be both difficult and extremely time consuming to differentiate during the initial survey. The non-water use areas include: sidewalks; public highways and roads; farm access roads; vacant lots; tank farms; oilfields; quarries; gravel pits; storage yards; railroad rights-of-way; miscellaneous impervious areas; and miscellaneous non-irrigated farm areas.

In the past, the DWR has employed two means of effectively subtracting out these non-water use areas. For agricultural areas appropriate percentage factors were determined from detailed surveys of representative sample plots. In urban regions, the net areas were derived through estimating the percentage of non-water use lands. A traditional detailed survey was time consuming and therefore costly. The variation within most of the general land use types indicated the need for an extended number of surveys in order to obtain a representative reduction factor.

4.3.2.1.1 Sample Selection and Area Computation

Prior to sample selection and analysis, a study was carried out which analyzed the land use classification system for which reduction factors were to be derived. In this case it was the eight-class, first-level system used by the DWR in the Upper Santa Ana region. The study provided information on the variation within each land use class that needed to be considered for sampling when the overview of the study area was made.

The method of sample selection was another preliminary consideration. To permit the use of statistical sampling methods and arrive at an acceptable reduction factor, the statistical population and distribution of all significant variations would have had to be determined. Because such information was not available and not easily attainable, it was decided that representative samples would be selected in order to provide reasonably comprehensive representation of all land use within a land use type.

Sample selection proceeded with a general overview of land use in the drainage basin using CIR imagery from NASA mission 164 (1:60,000) and NASA-Ames mission 72-112 (1:132,000). Relatively small scale imagery permitted a comprehensive complete photographic impression of the study area to be obtained. After the general distribution of land use and the types of variation that needed to be sampled had been noted, representative sample plots were located on larger scale imagery according to mechanical limitations of analysis and the availability of imagery. Smaller scale imagery was suitable for recognizing and delineating extensive use types such as shopping malls and agricultural areas. Larger scale imagery was needed for use types with fine

details, such as residential and educational types. Large-scale imagery used included: 14 July 68 (1:8,000); 13 July 70 (1:12,000); 25 May 73 (1:20,000); and 24 May 68 (1:60,000).

The imagery containing each plot was placed on the Kargl Reflecting Projector and enlarged. The boundary of each plot and the water use area within it were traced onto mylar, a process which produced a spatially correct but nevertheless schematic diagram of polygons on which non-water use could be analyzed.

The process of schematic analysis involved placing the schematic on the digitizing table and recording (x,y) values for each vertex to an accuracy of one-thousandth (.001) of an inch. Having compiled the vertices for each polygon, the analyst computed its area on a programmable calculator. The sum of the water use polygons was subtracted from the total area of the sample to obtain the ratio of nonwater use area to total area. The ratio was then used to calculate a percentage reduction factor for the sample. The arithmetic mean of the percentages (for all the samples of the same land use type) was the factor used in each instance to reduce the gross water service area to net water service area.

4.3.2.1.2 Analysis of Results

The most effective way to analyze the strengths and weaknesses of a new problem solving technique is to compare it with previous methods. In order to be acceptable, a new approach must offer significant advantages of efficiency and/or accuracy yet have no significant disadvantages which would outweigh such advantages. Emphasis here is given primarily to comparing the results of the UCR method with those of the DWR method and analyzing the variables to determine differences. The methods and results of the DWR are used, however, only as a means for analyzing the UCR method.

The problem solving format outlined in the preceding section was employed in selecting thirty-one sample plots in the Upper Santa Ana Basin. The study area and the location of these plots are shown in Figures 4.6 and 4.7. These samples were considered to be characteristic of the land use variation and thus should provide representative reduction factors. The reduction factors thus obtained are compared with those used by the DWR in Table 4.3. The discrepancy between the reduction factors immediately raises questions as to possible causes.

Possible causes for the discrepancy are found in three general areas:

1) land use change, 2) the sample base problem, 3) method error. Each of these possibilities is examined.

1) Land Use Change

A basic tenet about land use is that it is a function of man's actions. As these actions change through time they produce changes in land use morphology. The overt signs of these changes are seen in both convergent and divergent trends in human activity (such as an increase in the concentration of roads,

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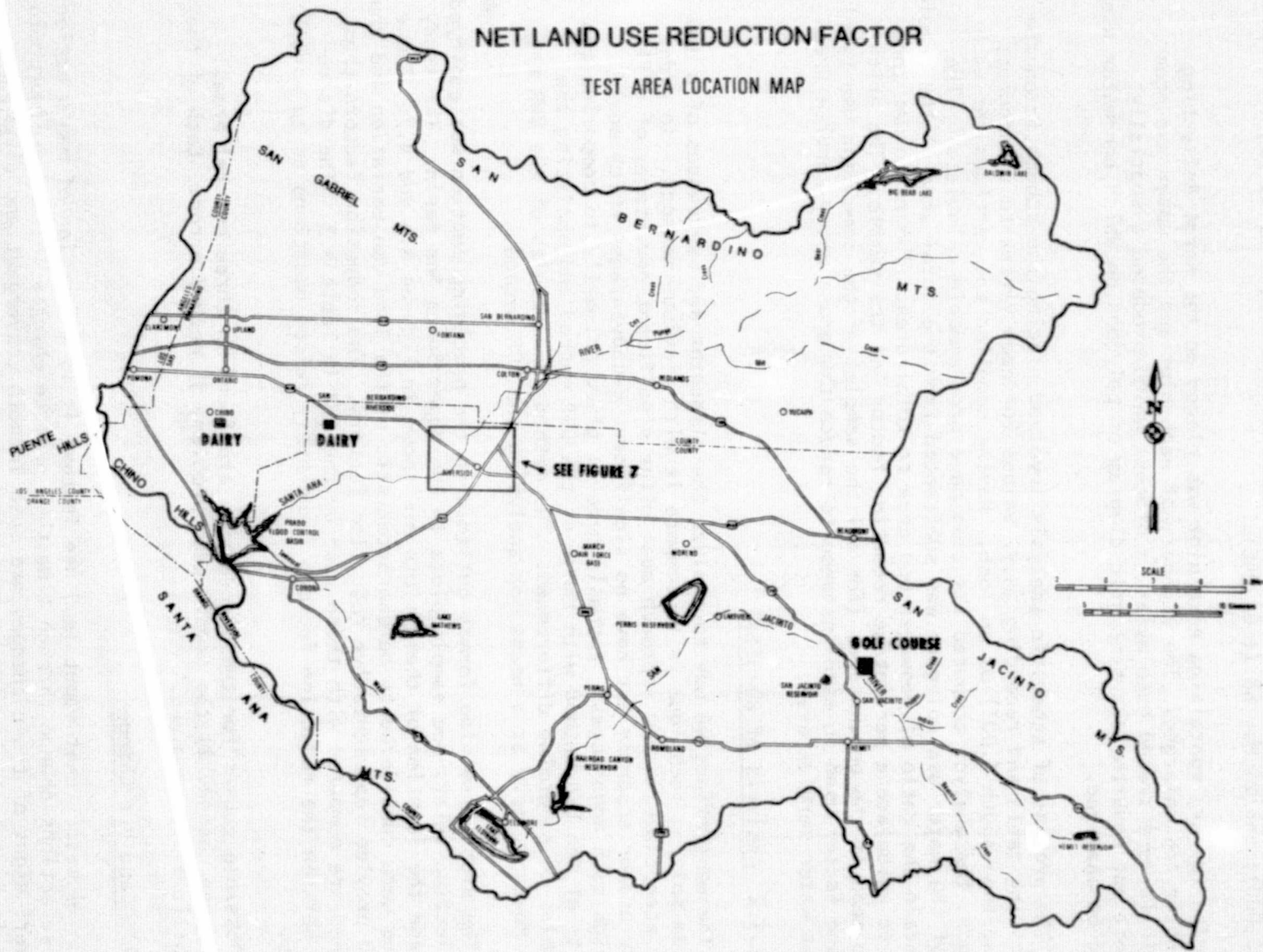


Figure 4.6. Location of Sample Test Sites Within Study Area Factor Used

RIVERSIDE AREA:
SAMPLE DISTRIBUTION
AND LAND USE TYPE

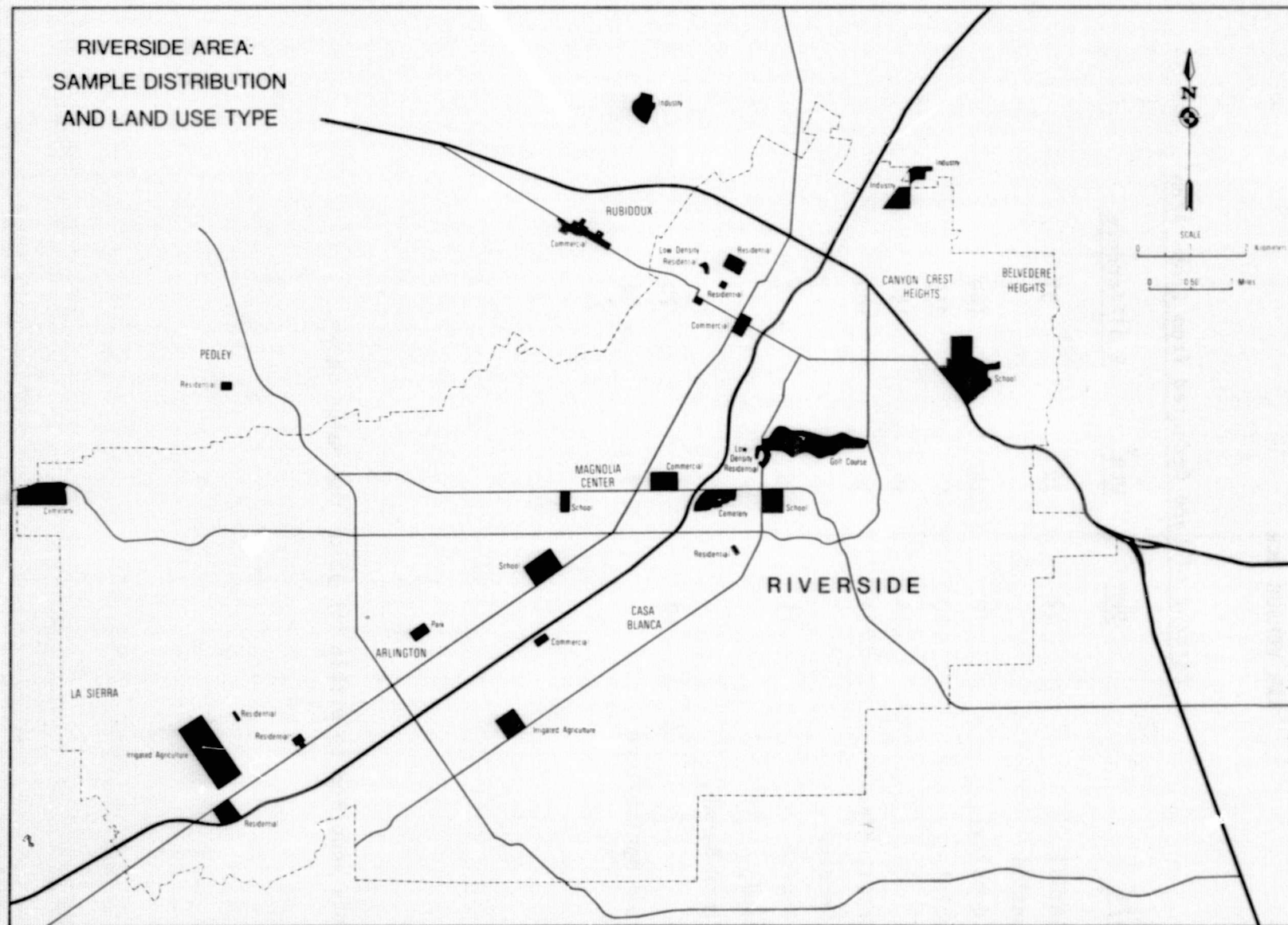


Figure 4.7 Area location of Sample Test Sites for determining Net Reduction Factor used to derive Net Water Use Area from Gross Land Use.

Table 4.3
REDUCTION FACTORS: METHOD COMPARISON
DWR VERSUS UCR

<u>Percent of Land Deducted from Gross Area</u>			
<u>LAND USE TYPE</u>	<u>DWR</u>	<u>UCR*</u>	<u>% difference</u>
Residential	22	29	32
Residential (low density)	10	24	140
Commercial	20	63	215
School	15	36	140
Industrial, Mfg.	25	50	100
Park, Cemetery, Golf Course	15	15	0
Farmstead, Livestock Ranch, Dairy	10	8	20
Irrigated Agriculture	5	9	80

* Measurements accurate to within (\pm) 5% of the value shown.

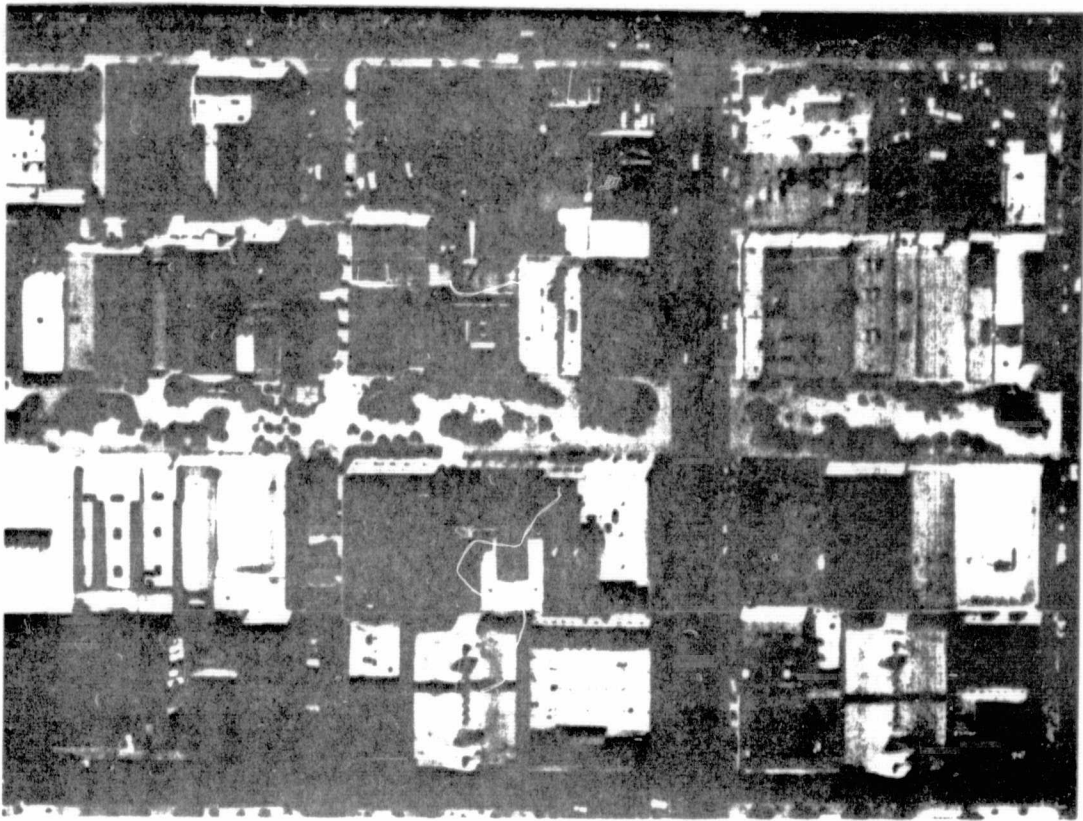


Figure 4.8a. Photograph of portion of Riverside Central Business District showing 49% of the area in impervious sidewalks, streets, and parking lots.

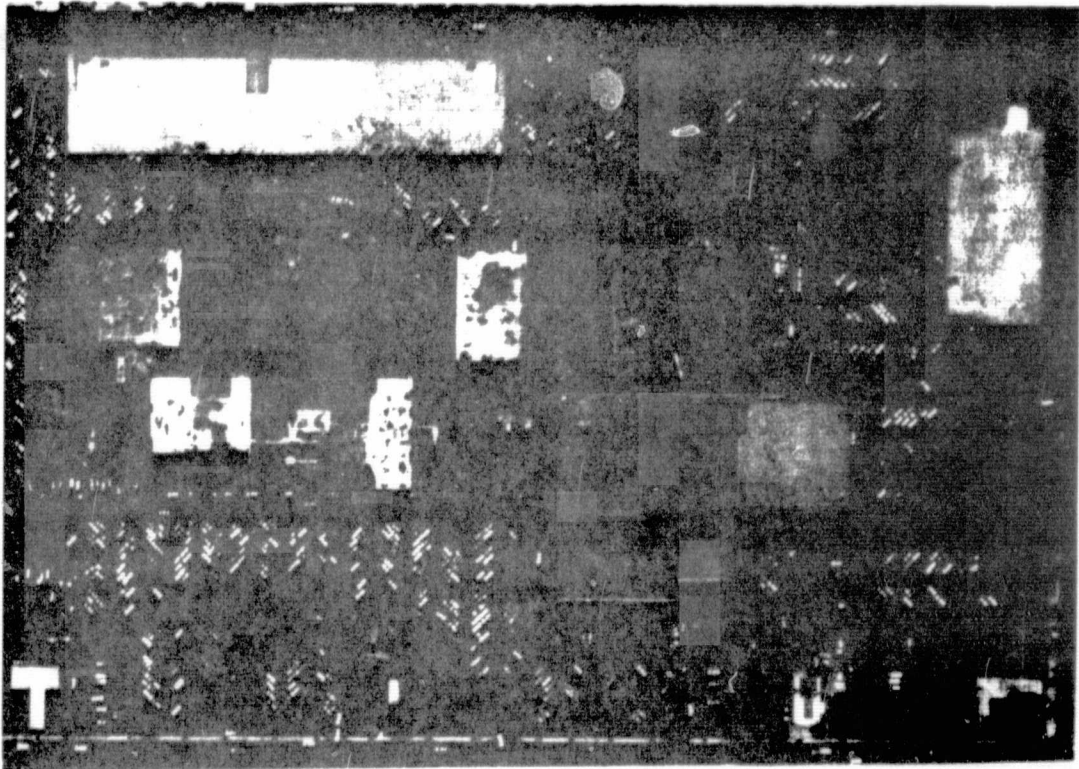


Figure 4.8b. Photograph of Riverside Plaza regional shopping center showing 67% of the area in impervious parking lots.

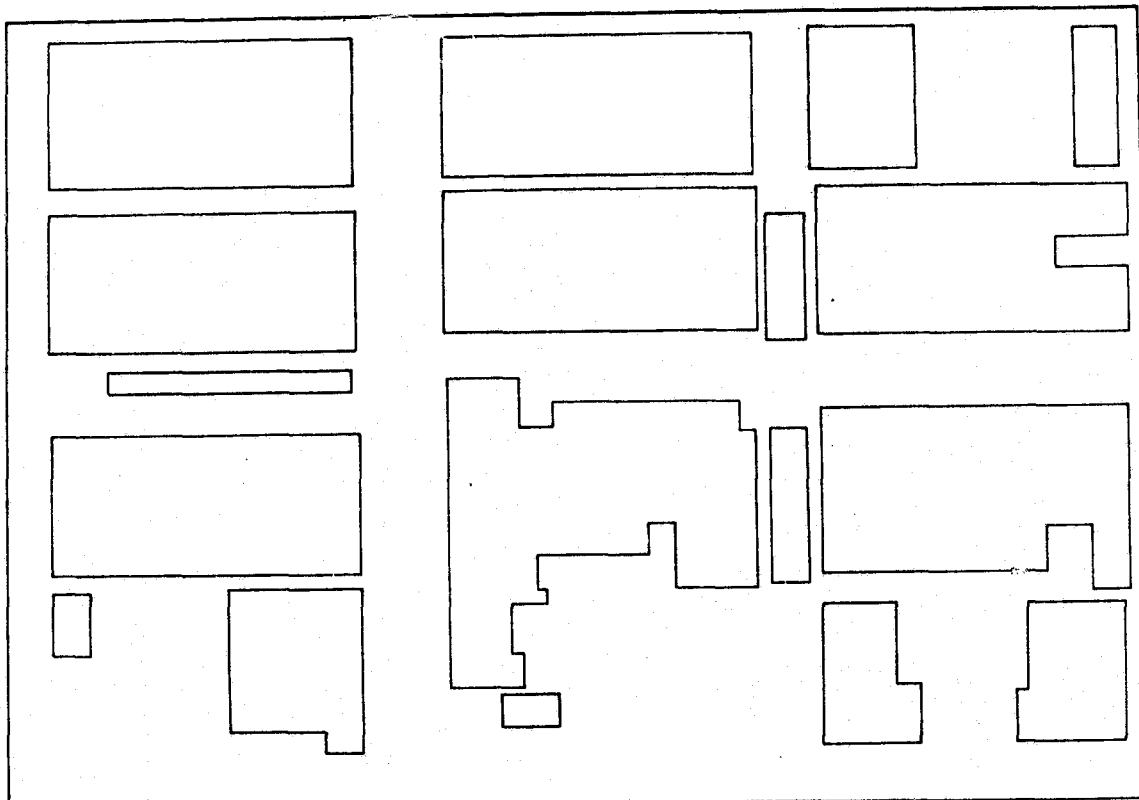


Figure 4.9a. Schematic drawing of Riverside Central Business District (CBD) outlining impervious areas used to determine the Net Reduction Factor for calculating the Net Water Use Area from the Gross Land Use area.

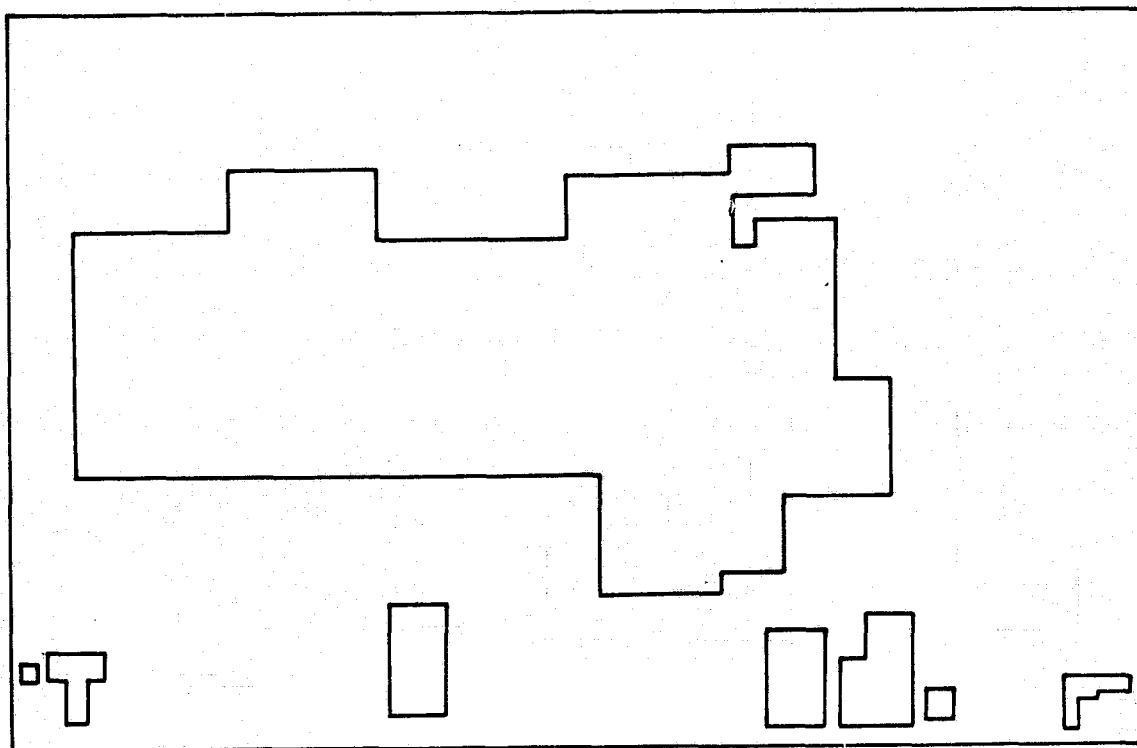


Figure 4.9b. Schematic drawing of the Riverside Plaza regional shopping center contrasting the difference in non-water use parking areas to the above CBD area of downtown Riverside.

houses, etc., and the abandonment of the central business district (CBD) in favor of shopping malls). More roads, wider streets, larger parking lots all increase the percent of nonwater use area. The effects of these changes as they relate to nonwater use areas are illustrated by comparing a CBD with a shopping mall, as in Figures 4.8 and 4.9. The percentages of nonwater use area for the CBD and the mall are 49 and 67 respectively. Such a shifting land use pattern makes it necessary to update reduction factors with each new water use survey. The fact that these land use changes can most effectively be monitored and evaluated by remote sensing techniques has been demonstrated by several NASA projects carried out by our Geography program here at the University of California, Riverside.

2) The Sample Base Problem

The goal of sampling is to arrive at a representative reduction factor without having to evaluate the entire study area for non-water use. A representative sample base consists of the number of samples that are required to produce a reduction factor that will be representative of all the variations within the general land use type. It is necessary, until detailed surveys of each variation are available, to rely on the skills of the investigator to establish a representative sample base. The investigator is limited in the number of samples he analyzes by the resources available to him. It is important that the method of analysis used by the investigator not restrict the number of samples to less than a necessary representative base.

The possibility of a less than representative sample base producing variation in the percentage reduction factor is well illustrated in a comparison of the thirty-one samples analyzed by the UCR method. Within most of the general land use classes the difference between the individual variations is sufficient to give a wide range of percentages of nonwater use area. The significance of each variation as it is added to the sample base is shown by calculating a cumulative mean reduction factor. While some samples have relatively no effect on the cumulative mean, each sample represents a significant variation of land use and as an addition to the denominator in the mean calculation, each is significant to the final product. The representative character of the reduction factor is insured only when all significant variations are represented.

3) Methods Error

The use of an analysis method is based on the assumption that the method will produce results of acceptable accuracy. The most critical question that can be asked when differences appear in the results is that of the possibility of inherent error in one of the analysis methods. The UCR method is based on the schematic, which to a degree is a generalized form of reality. A study of the different areas where error might enter the process of schematic analysis includes scale of the imagery and human error.

a) Scale of the Imagery

The physical characteristics of different land use types combine with imagery resolution and drafting skills to place an upper limit on the

scale of imagery that can be used to produce the schematic. There appeared to be no problem in producing a schematic from imagery with a scale of 1:60,000 when the land use sampled was of a block nature such as a shopping mall. Residential land use, however, with long narrow linear areas of water use required a larger scale of imagery. The primary problem was with the width of the tracing line. Imagery appeared to be acceptable as long as the resolution was high enough to permit interpretation and legible tracing. The degree of generalization increased somewhat, of course, as the scale of the imagery was reduced. Greater generalization is illustrated by a decreasing number of vertices. To determine what effect increased generalization might have, three schematics were drawn using different scales of imagery for the sample area. A comparison of the results indicates a minimal difference in the reduction factor as shown in the following table:

THE MARGINAL EFFECT OF GENERALIZATION
PRODUCED FROM THREE DIFFERENT SCALES OF IMAGERY

Sample: shopping mall	Imagery scale	Number of vertices	Percent nonwater use area	Percent deviation from mean
C02A	1:12,000	56	67.7	1.04
C02B	1:24,000	52	66.7	0.45
C02C	1:60,000	46	66.7	0.45
			mean = 67.03	

b) Human Error

The accuracy of the schematic depends on the skills of the investigator in interpreting the imagery and in drafting the schematic. Because these are skills which may vary they provide a possible source of inconsistency in the analysis method. Possible significance of human inconsistency was evaluated by checking the duplicability of a single sample. This check was carried out by drawing three schematics of the sample plot at three different times from the same imagery. The results of the consistency check appear in the following table.

THE HUMAN ERROR FACTOR AND ITS IMPORTANCE TO ACCURATE REDUCTION FACTORS

Sample: residential	Reduction factor	Deviation from the mean	Percent deviation from the mean
A02A	31.1	1.0	3.32
A02B	28.6	1.5	4.98
A02C	30.6	0.5	1.66
Mean = 30.1		Range = 2.5	

The percent deviation from the mean was greatest for the second sample taken several months after the first. The result enforces the hypothesis that human error exists in the reduction factors. The significance of the error is represented by the 5% range in the reduction factors.

c) Efficiency of the UCR Method

The second prime consideration in evaluating a research method is efficiency. How does the new method compare with the old in its ability to get the job done? A time check on the UCR method demonstrated that it took an average of 1.25 minutes to draw, digitize and figure percentage for each city block of residential land use in the samples analyzed. Thus, approximately 72 minutes was needed in order to derive the reduction factor for an average block. To obtain a comparable figure for the traditional survey method personnel of the Department of Public Works were contacted. They stated that it would take a three or four man survey crew three or four days to make the necessary survey of the average block and a cartographer also would be needed, for three or more days, to draft a map from the survey crew's field notes and to calculate the areas with a planimeter. The total comes to 97-152 man hours. Comparing this figure with that of the UCR method, the UCR method is 81 to 125 times faster. The Department of Public Works also mentioned two other problems associated with the traditional survey. 1) the problem of gaining permission to carry out the survey on private land, and 2) the ability of the planimeter to give accurate figures in small area calculations.

d) Gross Water Demand Test

How significant is the difference between the Net Reduction Factor as determined by the UCR method and that used by the DWR? The generally higher reduction factors obtained by the UCR method translate into lower water use figures. However, do these variances occur in land uses that are signi-

Table 4.4

SAMPLE ESTIMATED WATER USE DWR vs UCR

CLASSIFICATION	GROSS AREA	WATER USE EST. ACRE-FEET*	DWR ACRE-FEET*	UCR ACRE-FEET*
Living Area	11,462	1.6	14,304	13,020
Industry	441	4.0	1,324	884
Commercial	1,014	1.3	1,054	487
Recreation	884	3.7	2,779	2,779
Culture	25	1.3	26	22
Transportation, Communication, Utility	1,248	.5	624	624
Services:				
Education, Government	1,085	1.1	1,014	763
Other	325	1.3	338	156
Resource (agriculture)	11,354	2.7	29,122	27,896
Undeveloped	11,677	.6	7,006	7,006
TOTAL	39,515		57,591	53,637
			6.9% difference	

WEST RIVERSIDE 7 1/2' MAP

* Acre-feet values are for a normal 12-month period.

ificantly small for the Santa Ana Basin, or do they occur in land use types which make up a large percentage of the land use of the basin?

A sample test area was selected from the completed portion of the land use mapping project. The Riverside West 7-1/2' quad sheet was selected (see Figure 4.3) as a representative urban-rural sample containing 15,992 hectares (39,515 acres). Table 4.4 reveals that a total water demand for this area would produce a difference of 476 hectare-meters (3,854 acre feet) per year between the two systems. That amount represents a difference of 6.9%. Allowing for possible errors in computation of the Net Reduction Factor and using 370 hectare-meters (3,000 acre feet) as the average difference per each of the 30 grid areas (Figure 2) dividing the basin, the gross water demand difference for the basin would still total 11,106 hectare-meters (90,000 acre feet)! With water rates ranging from \$10 to \$40 per acre foot this difference is considerable when calculated annually.

e) Conclusion

The primary advantage of the UCR method is to be found in the time efficiency which it provides. A more representative reduction factor for each land use class is insured in a shorter period of time due mainly to the more numerous and larger samples that can be used. The margin of error that may occur with area measurements on the schematic is offset by the fact that a larger sample is more likely to be representative of non-water variations. The total process yields a more accurate reduction factor than has previously been available.

The inherent limitations and errors in the Net Water Service area method have led the DWR to develop a quite different course for water use estimation. Based on an urban per capita water use factor, this new procedure relies on population and historic water delivery data to establish estimations of water demand.

4.3.2.2 Urban Per Capita Method

This estimation method, based on an estimate of the urban per capita water use, is a set of procedures which establishes a Gallons Per Capita per Day (gpcd) figure for urban and industrial water uses in each water service district. Its applicability is limited to those service districts whose reliable population and delivery estimates are available. Agricultural and non-urban water demand estimates may not be calculated by this method.

4.3.2.2.1 Department of Water Resources Methodology

Procedures as employed by DWR are as follows: 1) Annual deliveries are calculated; these include metered municipal and industrial use plus system losses, minus agricultural use and water sold to other utilities; 2) Population for a given year is calculated by deriving, from census data, persons per water service connection and/or persons per dwelling unit, as interpolated (straight line) between census years and multiplied by the number of water

service accounts or dwelling units. Where census data were not available, population estimates were provided by the water agency itself. Therefore, annual water production in terms of gpcd is given by the following equation:

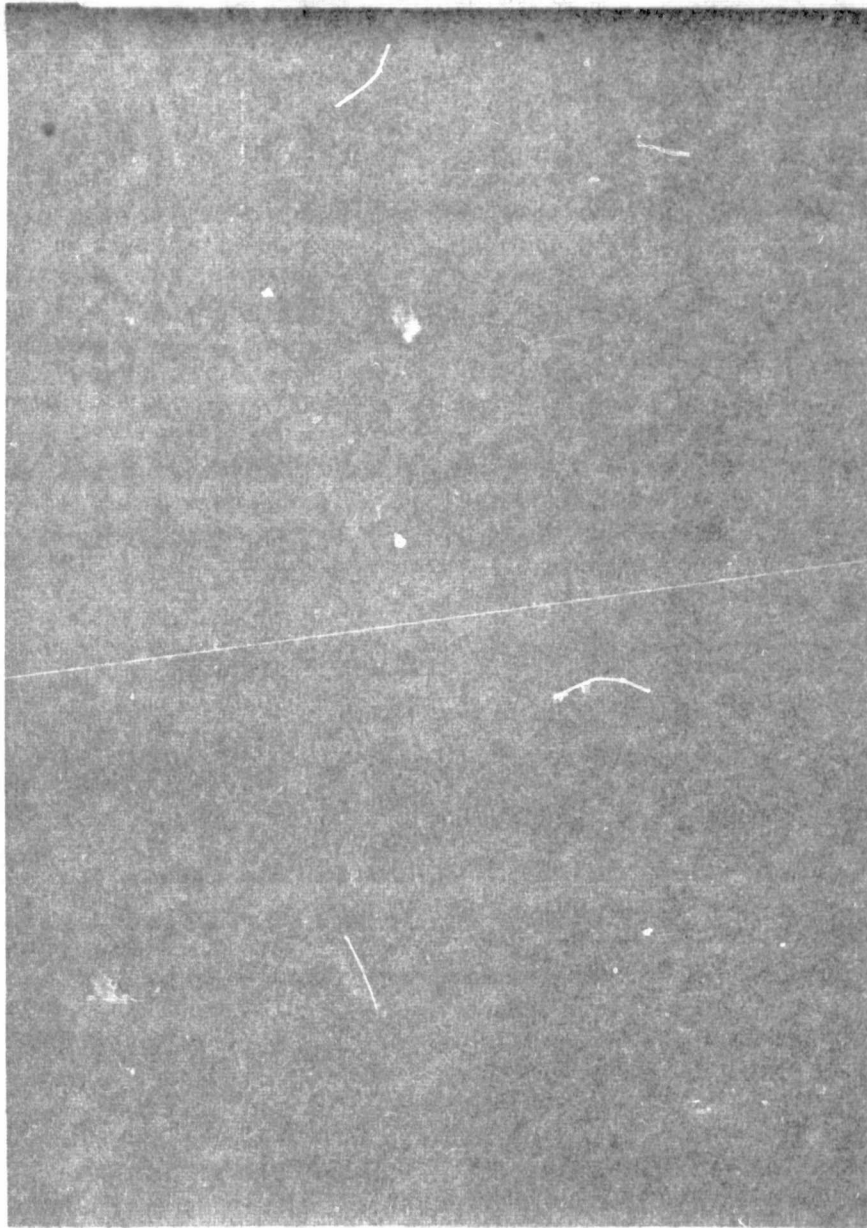
$$\text{gpcd} = \frac{\text{Annual Production (gal./yr.)}}{\text{Population}} \times \frac{1}{\text{days/yr.}}$$

Straight away one may see that the above procedure relies heavily on population data and dwelling unit counts for accurate estimates. A potential source of error comes as a result of the interpolation of census data for inter-census years. Population estimates of inter-census years may be approached in two ways. The first involves the use of various traditional statistical population estimation/prediction procedures, based on previous census data. The second technique provides a much better historic data base by actually observing population surrogates (i.e. dwelling units, population density, land use change) for the time period immediately prior to the year in question. This is accomplished most readily by the use of remote sensing techniques. In this regard, studies are now being formulated to demonstrate the use of remote sensing and available census data to provide accurate population estimates for inter-census years.

4.3.2.2.2 Population Evaluation Utilizing Remote Sensing

One such study addresses the need to analyze water use on a per capita basis and demonstrates the combining of data from the decennial census and high-altitude color infrared imagery. One value of this combining of data is to be found in the amplification of its geographic component. For example, it would be useful to show not only the extent of each census tract and its population aggregate but the actual area within each census tract that is occupied by various forms of land use. The use of high speed computers and readily available software, coupled with remotely sensed land use patterns, allows rapid and accurate calculation of land area used versus land area not used. In addition, determination of the area occupied by any of several land uses can be accomplished efficiently and may be delivered in a per capita format.

Population density has been calculated using a combination of census data and imagery for a sample portion of the San Bernardino area. The sample study involved the interpretation of the areas of residential land use from high altitude CIR imagery (Figure 4.10a). The residential pattern for each census tract was then converted into a computer compatible format by digitizing the polygon boundaries for residential and non-residential areas for the entire study area. An automated mapping program (CHORMAP) was then used to produce the map (Figure 4.10b) as well as area calculations for each census tract, and for each contiguous residential area within that tract. The residential area was then used instead of the census tract area to calculate residential population density within that census tract. The advantage gained is that the actual areal location of water demand is now known. This locational per capita data can be updated periodically by comparison of the mapped patterns against



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Figure 4.10a. CIR photo of San Bernardino, California showing actual living areas as related to the map of living areas overlaid on the 1970 census map. (NASA-Ames U-2 photo 8 Nov 1974. Scale 1:130,000)

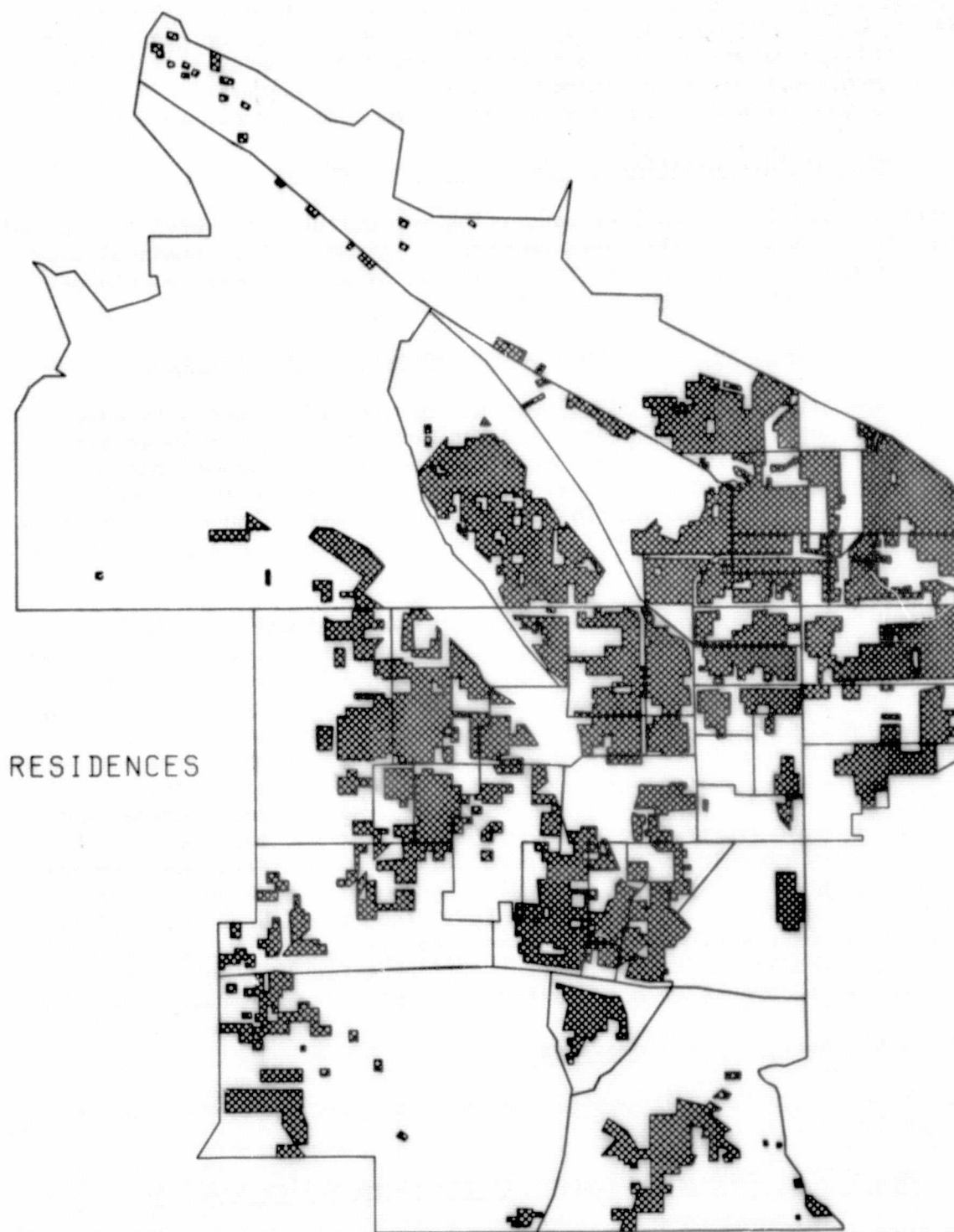


Figure 4.10b. Shade computer map of living (residential) areas of San Bernardino, California showing the specific areas of population as contrasted to population normally displayed as covering the entire census tract.

more recent imagery to check for changes in the residential pattern; then, by applying density figures to changed areas, a new population estimate may be made. This procedure is very simple to execute and nearly mistake-proof. The entire procedure can be performed by persons only superficially trained in the techniques of air photo interpretation and computer cartography.

4.3.3 Special Investigations of Agricultural Land Use

Three special investigations concerning agriculture have been programmed for this study. However, all three require a minimum of four seasonal over-flights. With our receipt of the fourth set of flight imagery in October, these investigations are not proceeding.

4.3.3.1 Remote Sensing System to Monitor Abandonment of Vineyards

The grape growing region of the Upper Santa Ana River Basin is concentrated between the cities of Ontario and San Bernardino on the Cugamonga Fan (see Figure 4.2). The vineyard area has undergone a change from rural to urban land use in the past decade, noted by the increase in the Kaiser Steel plant slag piles, the Ontario Motor speedway, expansion of the Ontario International Airport, conversion to industrial buildings, and even encroachment of housing developments.

To provide an early indication of conversion of vineyard lands, it is desirable to establish a monitoring system to detect such conversion. It is believed that the U-2 imagery is particularly suited for this task. The shifting trend is first indicated by the abandonment of vineyards which have probably become non-profitable due to high taxes, high labor costs, and decreased demand for certain types of wine grape. Active vineyards are readily detected from imagery by the clarity of appearance of access roads, differences in seasonal moisture due to irrigation practices in the summer months, appearance of ground cover (to prevent blowing sand) and weeds, and the general texture of the full-growing vines. Already it has been determined from the March imagery that it is impossible to distinguish active vineyards from abandoned vineyards in the wet spring months. The other three seasonal flights will be studied to determine the best season for detecting the abandoned vineyards. Grapes require .26 hectare-meters (2.1 acre-feet) of water per season, so with large abandonments it could affect the total demand considerably.

4.3.3.2 Other Agricultural Investigations

Two other agricultural investigations will be discussed under future studies section.

4.3.4 Monitoring the Waste Disposal of the Chino Valley Dairies

The area of the lower Chino and Riverside sub-basins of the Upper Santa Ana River Drainage Basin (lying between the cities of Ontario to the north and Corona to the south, Figure 4.2) encompasses an intense areal concentration of dry-lot dairies. The dairies are a distinctive land use easily recognized on the NASA high altitude U-2 imagery. Dairy practices in the region

are fairly uniform; thus monitoring of this land use should lead to accurate predictions of water consumption, waste production, and polluting effects on surface and sub-surface water quality. The pollution effects have become most important in the Chino-Riverside sub-basins and have led the State Water Quality Control Board to request assistance in developing a system to monitor the control of dairy pollution.

4.3.4.1 Ancillary Data

Data collection by the Water Quality Control Board has been designed to provide a check on individual dairies, and hence the following data are annually submitted by each dairy operator: 1) waste water in thousands of gallons per day; 2) animals (milk cows, dry cows, heifers, calves); 3) total acres; 4) waste disposal acres; 5) water treatment (pounds of softener salt), and; 6) manure (total produced and volume hauled away in thousands of cubic feet per year). The data have been machine encoded and preliminary statistics compiled. Collection of data on regional hydrology, geology, water quality and dairy practices has also been completed.

To facilitate data testing and photo interpretation, a reverse directory of the dairies in the basin was created from the Water Quality Control Board dairy report data. This directory allows a photo interpreter to relate dairies on the U-2 images to their operator's reported data, and to combine remote observations with that information. The directory is also being used to integrate dairy data into the land use information system being prepared for the entire region.

4.3.4.3 Image Interpretation

The 426 dairies in the Chino area have been identified from U-2 imagery. Preliminary maps have been prepared and are in the process of being encoded into computer format. Initial training required the use of 1:24,000 scale CIR imagery to assist in identifying the various components of the entire dairy. The milking barn located near the residence, as well as the circular drive (for milk trucks) and reflective front lawns, constitute most distinctive features (Figures 4.11a and 4.11b). The dark brown corral area with adjacent poled hay barns became the more distinctive features when interpretation was transferred to the 1:130,000 scale U-2 imagery. The remaining pasture area to the rear of the farm encompasses the major open area.

Tests of the reliability of estimates of waste production based on remotely sensed parameters have been made. The results of these studies indicate that waste production can be estimated within a range of $\pm 15\%$. It is felt that this accuracy is unacceptable; hence other parameters are being investigated to provide image data/waste production correlations. The previous tests used acreage as reported by the operators (i.e. total acres). Actual corral acres supplemented with hay storage area and other information about the physical layout of the dairy appear to have higher correlation coefficients in waste production prediction. The use of these parameters is currently being investigated.

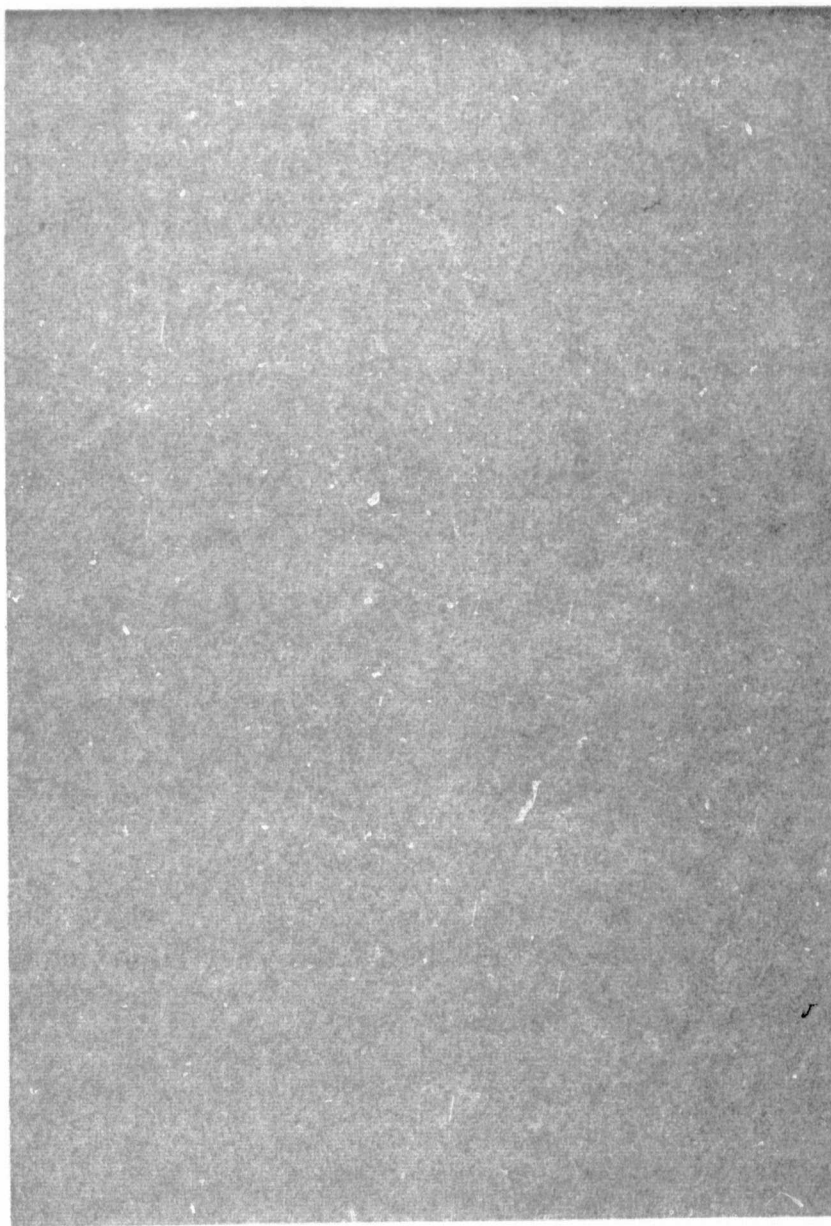


Figure 4.11a. CIR photo of southern portion of Chino Valley showing the concentration of dairies in this community. The typical sketch map in figure 4.11b is derived from the dairy complex near the bottom center of the photo between the two roads that converge just above the Santa Ana River. (NASA-Ames U-2 photo 26 Nov 1974. Original scale at 1:32,000. Photo scale 1:22,500).

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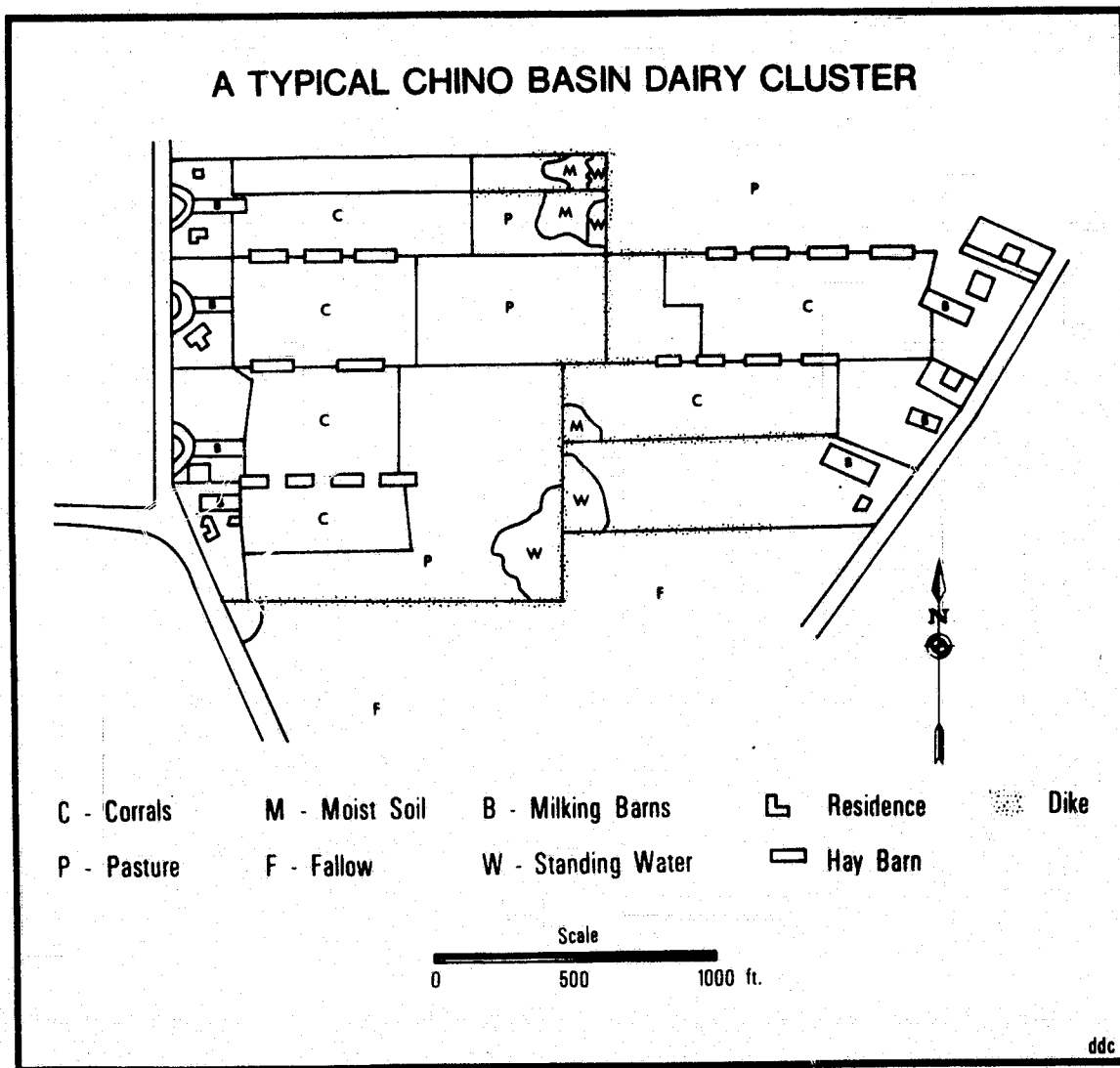


Figure 4.11b. Sketch map of a typical Chino Valley dairy cluster. Note that the areas labeled W for standing water and M for moist soil indicate areas where runoff water is being impounded.

Table 4.5

CHINO SUB-BASIN DAIRY POLLUTION STATISTICS

(426 Dairies - 1973)

	COWS (Equivalent)	ACRES	DISPOSAL ACRES	WASTE PRODUCTION TOTAL (Gallons)		NITRATES (lbs)	
				Daily	Annual	Daily	Annual
Regional Totals	176,077	18,217	11,838	8.28×10^6	3.02×10^9	311,656	1.14×10^8
Average Dairy	413	42.76	27.79	19,411	7.09×10^6	731	266,819
One Cow (Equivalent)		0.104	0.067	47	17,155	1.77	646
One Acre	9.67		0.650	454.5	165,893	17.12	6249
Avg Disposal Acre	14.87			698.9	255,095	26.32	9607

Since cow populations are regulated as to density, and total herd sizes are regulated by production stabilization programs, the estimating methods developed for present conditions in the Chino basin should have validity for other dairy areas in southern California, and be subject to only minor errors related to changing dairy practices.

4.3.4.3 Dairy Waste as a Source of Water Pollution

Most dairies in the Chino sub-basin have 150 to 400 cows. A substantial number of very large dairies have up to 700 head of cows. The total cow population at the end of 1973 was 176,077 located on 426 dairies. 135,501 of these cows were in milk production. Table 5 outlines the dairy population and concurrent waste production for the Chino sub-basin.

Wash water and other wastes produced by the dairy operation yield a daily out-flow containing an average of 1162 ppm of total dissolved solids (TDS). Rainwater from corral areas can have a similar high pollutant content. An experimental rain simulation of 7.6 mm (0.3 inches) runoff yielded water which had a pH factor of 8.9; 7% TDS, 17.5 mg/l ammonia (NH_4^+), and 4.5 mg/l nitrates (NO_3^-).

It has been the alarming nature of statistics like the above that has led the Santa Ana Regional Water Quality Control Board to prohibit any surface runoff from dairies in the Chino Basin, except runoff waters caused by 20-year floods. To prevent runoff, the Board has required the dairyman to construct settling ponds and/or dikes on the downslope of their farm. It is the ponds or dikes that become detectable from the CIR imagery. Wet soils and standing water are easily detectable from U-2 imagery. It appears that a remote sensing monitoring system can be established.

4.4 Future Studies

The Riverside campus proposed to study two different areas upon renewal of the grant.

4.4.1 Water Demand Studies

Three sub-studies will lead to the completion of the on-going study of the Long Term Water Demands of the Upper Santa Ana River Drainage Basin.

4.4.1.1 Water Demand Model

Encoding of the remaining maps of the basin will be completed by the end of the current contract year. Initial testing of the model and comparison of results can then be made with the Department of Water Resources. At that time, the cost-benefits can be more precisely computed and evaluation of the system can be made. The development of housekeeping tasks for the model will be accomplished in the forthcoming year with the updating techniques being the prime work.

4.4.1.2 Refinement of Agricultural Parameters

Perhaps the most important drivers of the water demand model are those involving agriculture. Three projects need completion.

a) Vineyard abandonment Monitoring

If this study has not been satisfactorily completed prior to the end of the current year, it will be necessary to complete development of the surrogates that will permit early detection of vineyard abandonment as outlined in previous sections. This study has been delayed awaiting receipt of four seasons of imagery.

b) Identification of Permanent Citrus Crops

Another crop that requires year around irrigation and thus has a stabilized water demand is citrus. Like the vineyards, the citrus groves have been subject to gross displacement. It was first thought that much of the citrus activity would move to the Central Valley of California, but this has not been the case. Riverside County now has more acreage in citrus than it had at the height of the citrus era (1930-40). Citrus cooperatives and corporations have chosen to move to the fringe areas and remain in the more climatically suited Riverside-San Bernardino area. The availability of new sources of water, although more costly, has encouraged this decision. A system of monitoring by remote sensing needs to be established to detect this trend of relocation of citrus as an aid to better water and crop management.

c) Determination of Period of Fallow Season of Irrigated Fields

It has been previously stated that the DWR desires to improve its estimate of water demand of irrigated fields. However, they have only instantaneous data collected as much as ten years apart on the number of fallow fields. The current method of estimating is to list all fields that are fallow at the instant of the decadal inventory as "non-water use." Irrigated fields in production at the time of inventory are counted as demanding the full water demand for the full annual term. Hopefully, the variations between the producing fields and the fallow fields will cancel any errors that exist.

It is hoped that, through studies of the four seasonal flight images, an average period of the fallow season can be established and thus permit the water demand estimated for irrigated crops to become a more realistic value.

4.4.1.3 Polygon Overlay/Update

A land use information system can be differentiated from a land use inventory in two basic ways. First, the data, both qualitative and spatial, in a land use information system are organized in such a way as to facilitate

machine analysis; be it area calculations, overlays, etc. Secondly, a land use information system is capable of being updated. That is, the basic structure of the system is timeless because new information can be added and obsolete information deleted with ease. Because any geographic information system must contain both spatial and qualitative data, the update capability integrated into a land use information system must be able to deal with both horizontal (spatial) and functional (qualitative) changes. Studies are presently being commenced which will establish optimal software architecture for accomplishing the updating via 'overlay' technology.

4.4.1.4 Chino-Sub-Basin Dairy Water Quality Control

The most immediate problem in monitoring the water quality in the Chino Sub-basin is to determine the scale of imagery required to detect presence of ponds and/or dikes on each dairy farm. The ponds and dikes, as indicated in a previous section, are to contain the runoff waters from each dairy operation. Besides flying a sensor package containing longer focal length cameras for higher resolution, we also intend to request at least one flight of the infrared thermal scanner. It is believed that a thermal flight will aid in determining water content of the soils on each of the dairies, which may indicate the effectiveness of waste disposal.

Completion and updating of the data collection, both imagery and ancillary, will allow development of numerical estimates of the hydrologic impact of dairying in its present form, and lead to the development of predictive techniques to assess the effects of changes in dairy practice, distributions, or intensity. The models of dairy impact can be used to produce, through computer graphics, maps of the various aspects of the dairy water use problem (e.g.: projected ground water draw-down for an additional dairy distribution in the basin).

Once the correlative models have been developed, they will be tested to determine how well imagery interpretation can be used to monitor dairy land use. "Postdiction" will be attempted, in which the dairy parameters of an earlier date will be applied to the models and the results compared against records of well depth, water quality, and supply for that date. In addition, a cross-regional study will be made to determine how well the Chino data can be used to predict water use, waste production, and other factors in the San Jacinto Area (Southeast region of the Santa Ana Basin).

It is believed that a study of the paleogeography of the Santa Ana Basin through the use of LANDSAT and U-2 imagery will be helpful in predicting modern subsurface flow and recharge conditions. It is the subsurface sediments which now provide a medium for ground water flow that were laid down by surface waters and mark the routes and boundaries of ancient drainage. Groundwater flows as a response to hydrostatic conditions and subsurface flow routes frequently coincide with buried ancient surface drainage routes. Therefore, the ancient surface hydrologic system will provide a basis for an understanding of the modern geohydrologic system. The importance of understanding the subsurface flow is to determine the rate of possible underground pollution

(i.e. high nitrates) flowing to the Prado Dam area. The character and geometry of the Santa Ana Drainage Basin have undergone extensive changes during the last 2-3 million years. The Transverse Ranges (San Gabriels and San Bernardino Mountains) constituting the largest portion of watershed of the Santa Ana Basin have been uplifted during this time. In addition, deformation of the southern Coastal Ranges, which constitute the basin's southwestern boundary, has continued at a fairly constant rate, and tilting of the Perris block between the San Jacinto and Elsinore faults has taken place.

It is proposed to reconstruct generally the ancient (Plio-Pleistocene and Pleistocene) drainage of the Santa Ana Basin through reconnaissance mapping methods utilizing satellite and high altitude aircraft imagery.

4.4.2 Remote Sensing Studies of the Southern California Coastal Environment*

In the questioning of various agencies concerned with the programs of the Southern California Coastal Region, it has become evident that each agency has a concern about some particular facet of the environment. The environmental problem that has lead to the establishment of the Air Quality Control Boards is visibly evident in Riverside most everyday. The previous section has described at length the problems of the Water Quality Control Boards. A coastal commission has been established to insure that our future generations may enjoy our coastal beaches. Control boards are attempting to restrict the construction of power plants, refineries, deep sea ports for super tankers, off-shore oil drillings, ad infinitum. Another very difficult problem lies in the selection of the method or methods used to move large densities of population from the nodal points of living areas to the nodal points of commerce and industry; in fact, the establishment of these nodes themselves constitutes an important problem. All of these later mentioned efforts to control various aspects of living are to protect the environment. What can remote sensing do to solve these environmental problems?

4.4.2.1 Development of a Coastal Geographic Information System

A representative of the Southern California Association of Governments (SCAG) concerned with the transportation problem stated that there is an overwhelming amount of data with a multitude of time bases. What is needed is an organization of the data in a common time frame. Conventional High Altitude Imagery can provide base data around which a Coastal Geographic Information System can be established.

It is proposed that the Riverside Campus make a feasibility study this next year for a Coastal Geographic Information System utilizing U-2 CIR imagery as a base for the data.

4.4.2.2 Studies Utilizing SO 224 Film

The recent experiments with the Kodak SO 397 water penetration film as described in the November 1974 issue of the Photogrammetric Engineering indicates there such film offers great possibilities for studying the coastal

*The six tasks identified will not be limited to U-2 sensor packages but will use ERTS-1, LANDSAT, and NOAA satellite imagery where appropriate.

environment

It is proposed that the Riverside Campus study the uses of this water penetration film in the immediate coastal environments to include: coastal landforms; beach erosion and depositions; marine vegetation (kelp) inventory and growth or decline; monitoring of harbor and possibly offshore water pollution; and other target of opportunities.

4.4.2.3 Environmental Studies Utilizing Thermal Infrared Imagery

The acquisition of a thermal infrared scanner has added a new dimension in sensors available on a continuing basis to environmental studies in California. The power plant operation problems, the refinery problems, and the automobile freeway problems (all environmental pollution concerns) are responsive in a very different way, when imaged by a thermal scanner. The thermal effects of these heat emitters may lead to a better understanding of their effects on the environment.

It is proposed that the Riverside Campus study the effects of heat emission from various sources of hydrocarbon emissions to determine the effects on the environment.

4.4.2.4 Coastal Lagoon and Marsh Study

The ria coast of southern California, from Newport to San Diego, is marked by uplifted beach terraces, cut by sharply-incised valleys which have been filled with sediment as a consequence of the Holocene (post-glacial) eustatic rise in sea level. Where these rivers meet the ocean, the cliffed shoreline opens into a broad flat, usually fronted by a sandy beach with a lagoon behind it. Varying rates of discharge from the streams cause some of the beaches to be breached, and others to fully impound the streams flow.

These marsh-lagoon areas, highly active biological environments, are seriously affected by coastal land use. Sedimentation, pollution, and beach erosion can be stimulated by changes in neighboring land use, while they can be permanently changed by direct development, such as dredging, filling, channeling and other "reclamation" activities.

Structural features of coastal marshes and lagoons are clearly visible on CIR imagery even at typical U-2 scales. Remote sensing of these areas will make possible an inventory of this valuable tideland environment, and evaluation of the present level of disruption due to man's activities. Higher resolution imagery (i.e. image scales between 1:10,000 and 1:30,000) should be investigated for properties of vegetation distinction as well as providing a basis for more detailed geomorphic analysis. A high level of information extraction might also be possible using photo-enhancement techniques such as density-slicing or custom-tailored filter packs.

4.4.2.5 The Surf-Zone: Beach Sand Movement and Changing Beach Morphology

Intensive development of the southern California coastline has had a profound effect on the "sediment budgets" of the beaches. Groins, jetties, seawalls, marinas, harbors, and flood control projects all influence local beach morphology and the movement of beach sand.

Many beach forms, especially rhythmic features such as cusps, are clearly visible in remotely sensed images. These forms, especially when viewed with moderate water penetration to show sub-surface turbidity, can tell much about near-shore coastal currents and allow the interpreter to map sediment movement along natural coastlines and around man-made barriers.

Knowledge of sediment movement is valuable for planning and management of safe marinas and harbors, as well as being useful for planning of recreational beach uses. In addition, remote sensing offers the most practical way to monitor seasonal changes in the beach sediment system, and to identify areas that are exceptionally vulnerable to storm-wave erosion, a major cause of damage to beach front property.

4.4.2.6 Identification of Energy Resources Hazardous to the Coastal Environment

The California Energy Resources Conservation and Development Commission has been directed to determine marine and coastal vulnerability, especially to accidents resulting from offshore and on-shore oil and gas development and associated shipping and transfer operations. The use of remote sensing is essential in identifying the areas of potential hazards. It is quite possible that this effort can become jointly funded.

It is proposed that the Riverside Campus make a study which identifies on-shore/off-shore energy resource hazards that are potential hazards to the coastal environments.

CHAPTER 5

SOCIO-ECONOMIC ASPECTS OF REMOTE SENSING TECHNOLOGY

Co-Investigator: Ida Hoos, Berkeley Campus

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Chapter 5

Table of Contents

	<u>Page</u>
5.1 Background	5-1
5.1.1 The Technology-Society Interface	5-2
5.2 Current Activities	5-3
5.2.1 Some Specific Findings	5-5
5.2.2 Benefit-Cost Analysis as a Tool in Evaluation	5-11
5.3 Plans and Prospects	5-14

CHAPTER 5

SOCIO-ECONOMIC ASPECTS OF REMOTE SENSING TECHNOLOGY

CO-INVESTIGATOR: IDA HOOS, BERKELEY CAMPUS

5.1 Background

The management of California's water resources continues to be the focus of the research activity of the Social Science Group, which is an intrinsic part of the Remote Sensing Integrated Project. We study the institutions and mechanisms through which water policy decisions are made and implemented; we establish and maintain rapport with persons responsible for making and carrying out decisions; we observe the societal forces* impinging on public decisions having to do with water resource management; and we explore the ways in which remote sensing and related technology might be utilized in the management of water resources. We view this last-mentioned item as especially significant in light of the findings and recommendations of the Committee on Remote Sensing Programs for Earth Resources Surveys (CORSPERS).

This Committee, a highly prestigious body, was appointed by the National Research Council's Commission on Natural Resources, which acted in behalf of the National Academy of Sciences. With their objective an assessment of the usefulness of remotely sensed data from earth resource surveys and environmental monitoring, the Committee reviewed the results achieved by investigators using data from LANDSAT, supplemented by related sources. Their report,** comprehensive in coverage and supportive of the technology, was explicit in its recommendations. Prominent among the concerns of the Committee was the role of resource managers. In fact, the centrality of the "user community" was stressed in various contexts in the Report. The point was made that, despite the significant resource and environmental information that researchers could extract from the LANDSAT data, there exists a considerable gap between this technological capability and the "operational user community." In their words, "A joint effort by the user community and remote sensing technologists is needed to bridge this gap. The Committee endorses the recent efforts by the user agencies and NASA to initiate joint quasi-operational or demonstration projects".***

* These include prevailing economic conditions, attitudes toward environmental preservation, credibility of various information sources, policies pertaining to growth, and political positions on resource management.

** National Academy of Sciences, Commission on Natural Resources, National Research Council, Committee on Remote Sensing Programs for Earth Resource Surveys, Remote Sensing for Resource and Environmental Surveys: A Progress Review - 1974, Washington, D.C., 1974

*** Letter from Arthur G. Anderson, (Chairman of the Committee) to Dr. Gordon J.F. MacDonald (Chairman, Commission on Natural Resources), August 5, 1974.

5.1.1. The Technology-Society Interface

NASA has for many years been cognizant of the need to forge a link between its technological accomplishments and the community most likely to benefit from them. Whether under the official title of Technology Utilization or some other designation, the notion of social utility has entered into many of NASA's missions, just as the technology assessment has been built into the research and experimentation stages of development.

NASA effort along these lines is embodied in the multi-campus University of California Remote-Sensing Project which, from its inception, has incorporated the utilization aspects of remotely sensed data into its overall research design. Working in tandem with the scientists and technical experts, the Social Sciences Group has been concerned with the social, cultural, political, and economic factors impinging on receptivity toward and utilization of the new techniques.

Monitoring the earth's resources from space represents a leap into the future technically. The promise is enormous, but the potential can be realized only if implementation occurs. Since it is evident that implementation does not take place in a social vacuum, the social scientists must "map the social landscape" as meticulously as the remote sensing expert establishes ground truth, in order to understand the why's and wherefore's of application and utilization. How, where, and in what form remotely sensed data can enter into and contribute to decision-making processes, what conditions affect receptivity toward new sources and forms of information, what are the criteria by which the data (and the technology) are assessed, and how the remotely sensed data may ultimately affect resource management -- all these form the area of inquiry with which the Social Sciences Group is concerned.

This area is, in essence, the interface between the technology and the society it has been designed to serve -- between the technical and the user communities. Upon the nature and viability of this interface the ultimate contribution of the technology depends. It is the vital link between the promise and the realization. This is a point long recognized by NASA in many of its endeavors and is implicit in the design of the Integrated Project, which carries on its research in close cooperation with the user community. The CORSPERS report underscores the need and importance of this orientation:

Remotely sensed information ultimately must find its way to a multiplicity of final users. These may be found at all levels of government, private industry, and university groups. For example, the field of water resource management and the issues of land use mapping and land use planning affect many federal, state, and local and private agencies. Effort by NASA and the Department of the Interior to arouse interest and stimulate involvement at state and local levels has been quite extensive. Primary emphasis has been directed at convincing state and local authorities of the usefulness of the present vintage of LANDSAT Imagery and at merchandising it. The very diversity of the user community makes establishing user requirements most difficult. At present, no comprehensive mechanism exists, but continued efforts to establish that user role are required.*

*CORSPERS Report, op. cit., p. 38

It is not the function or responsibility of the Social Sciences Group to develop the "comprehensive mechanism" CORSPERS refers to. However, because delineation, identification, and investigation of the user community are pre-requisites, we devote serious effort to establishing and implementing the channels of communication that will lead to better linkages. Our approach is practical and pragmatic; we seek no dazzling theoretical or methodological breakthroughs. While we use the "tools of the trade," i.e. simulation, modeling, and the like, where need and appropriateness are indicated, we expect to derive no magical formulas. At the same time, we deem it our obligation to draw upon our discipline and experience to examine and evaluate the models being offered as justification for courses of action taken or proposed.

In addressing the socio-economic and political aspects of water management, we seek to identify the real-life dimensions, for these are the sine qua non in public policy formulation and far supersede parochial and doctrinaire considerations. As has happened in the past and is bound to happen in the future, the management of water resources in California may appear to be as much a battleground for conflicting economic interests and political beliefs as a task for technical decision analysis. If so, this is the real-world environment in which policy must be made and lived with, and while it is neither our intent nor mission to dwell on controversy, it is important to note the divergent viewpoints that must be taken into account when decisions about resources are being made. And more often than not, the crucial issues under discussion may have enormous impact on water resource management but may come under such headings as land use planning and energy policy.

5.2 Current Activities

Consistent with our mandate and reflecting the suggestions of Dr. Peter A. Castruccio,* in his capacity as consultant to NASA, we have sought to trace the decision-making process in California water management. We have learned that to identify the decision-makers and to discover the kinds of decisions made and by whom is a task not too well or adequately served by reference to formal organization charts and tables, notwithstanding the plethora of them included in our preceding Progress Reports. One encounters a multitude of separate entities, which include agencies of the state and federal governments, local public bodies of many types, as well as departments of local governments. There is also the complex network of bureaucratic infrastructure, which interacts in diverse (and not always predictable) ways with appointed boards and commissions and treads a precarious course through the sometimes conflicting jurisdictional levels and entities, to produce a "decision tree" that actually bears striking resemblance to a bramble patch!

There is, moreover, the informal management structure, where "channels" are bypassed and actions are taken with only token reference to "the book". In government, as in industry, a great deal is accomplished, or stymied by this mechanism. Added to this are the wholly personal predilections, preferences, prejudices, and biases of managers. Idiosyncratic, often unpredictable and usually subliminal, these factors are nonetheless crucial in decision-making.

*P.A. Castruccio, "Comments on Report 'An Integrated Study of Earth Resources in the State of California,'" March 12, 1974

These observations should surprise no one familiar with large-scale organizations and, more especially, with a network of them, such as California's water industry. Where authority resides and what are the specific areas of responsibility reflect a long history in California policy and politics, with economic underpinnings, legal ramifications, and sociological overtones. The vast literature on all these aspects of California water resources attests to the complexity of the management process and warns against too facile reliance on "the decision maker" as anything but a convenient fiction, or on the "user community" as something other than a serviceable construct. There are many "decision-makers"; often, their precise identity depends more on the matter being decided than on their slot in the formal organization chart. Similarly, the "user community" is not, as the term implies, a monolithic body that behaves in a fairly unilateral fashion. Just as "the decision-maker" depends to some extent on the problem, so the "user community" is a hydra-headed aggregation, often taking shape with reference to the particular technology at hand. For example, a potential user community for remote sensing data in monitoring the Delta could be composed of environmentalists, conservationists, agribusiness representatives, water district managers, State water quality officials, Fish and Game people, and many more. As indicated in the CORSPERS Report,* it is to the multiplicity of final users that remote sensing techniques must demonstrate their usefulness.

Such being the case, we have set for ourselves the task of ascertaining in addition to the identity and location of the final users, the factors influencing receptivity toward the new technological sources of data and the conditions enhancing or impeding successful transfer of the technology from the experimental to the utilization stage. The period of relative quiescence as the new Administration in Sacramento assigns and initiates directorates, with the accompanying bureaucratic adjustments, has provided an opportunity for this investigation, which may prove useful to NASA not only in its satellite projects but also in any involving the transfer of technology. We may note that the present period of internal adjustment has put a virtual moratorium on such major construction enterprises as the Peripheral Canal, discussed at some length in our foregoing report. Since the new Director of the California Resources Agency does not make a recommendation to the Governor in so complex and controversial a matter as this without intensive review there has been a postponement. During the next year or two, additional information will be gathered so that a new look may be taken at overall state planning, with possible re-evaluation of the State Water Plan. There may be some basic changes ahead in need projections and such alternative courses as desalination and reclamation may be explored more vigorously.

In pursuing the line of inquiry into the multiplicity of LANDSAT users, we have continued to focus our attention on water resource management as the case in point, although it is clear that our conclusions will have wider applicability.

5.2.1 Some Specific Findings

Based on our observations, we can offer the axiom that a prime factor in utilization is specificity. (Stated in the private parlance of the professionals, the "ballpark" approach, with vague claims as to ubiquity, is useful only for "gee whiz" purposes and not when there is work to be done!) New technologies must prove themselves in every instance of use, and the "proof" must be fairly tangible and visible in relatively short time. These two conditions, i.e., tangible and visible, account for the widespread dependence of resource managers on cost/benefit measures that lend themselves to an assembling of supportive "facts" as a kind of rationale.

The case for specificity is illustrated by many of the projects being carried on by the University of California Remote Sensing Program (RSRP). The project using LANDSAT data to estimate the areal extent of snow* is especially germane, for it has served as a point of direct cooperative effort between the Social Sciences Group and the RSRP. As indicated in the 31 December 1974 Progress Report and further elucidated elsewhere in the current Progress Report, we have been jointly engaged in an analysis of the cost-effectiveness of remotely-sensed data as compared with more conventional sources. This demonstration exercise, focusing on the economic aspects of remote sensing as applied to water supply forecasting, further underscores the importance of specificity. In instances where a new technology is being offered as a potential substitute for and possible improvement over traditional methods, demonstration of reliability is essential. Here again, the Integrated Project provides an extensive array of examples.

The time element in availability of data is important for resource managers. Consequently, channels for dissemination of the remotely sensed data become a crucial matter in receptivity. Speed of availability and efficiency of distribution are vital factors in the coupling of any technological innovation to socially useful purposes. This is almost axiomatic but has particular relevance where information technology is concerned. Another factor affecting receptivity is ease of access. Here, we refer not to the efficiency of the delivery system but, instead, openness of access. Prospective users almost invariably ask about the secrecy associated with the gathering and dissemination of LANDSAT-type data. They express great relief upon learning that LANDSAT imagery can be ordered as easily as merchandise from a Sears Roebuck catalog.

Our inquiry into present procedures for obtaining information about natural resources from military satellites was prompted by the recent budgetary controversy over the future of civilian satellites. In order to compare the accessibility of the former, we investigated the conditions that must be satisfied for a potential user, i.e., a resource manager associated with a government agency, to obtain data from the Department of Defense. The personal security check, so searching as to require listing of even

* See Semi-Annual Progress Report, "An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques," 31 December, 1974, pp. 2b-13ff.

dismissed charges (under Violations of the Law), and establishment of the need-to-know, criteria for which were strangely elusive, contrast sharply with the mail-order openness of LANDSAT-type data -- and are likely deterrents to widespread acceptance. Perhaps the greatest barrier to utilization of data from military satellites is the official requirement that the information be so "sanitized" as to obscure beyond possible recognition its exact source. This anonymity goes counter to the accepted mode of "quoting chapter and verse" to authenticate a base for research or operation. The relative merits and demerits of military as opposed to civilian hardware were not our concern because (1) they were not strictly relevant to our research mission, and (2) diametrically opposite positions on the purely technical aspects in this debate have been taken by competent authorities. We were interested in learning whether potential users' receptivity was affected by openness of access. We found such to be the case. It therefore appears that this is a point of sufficient import that it should command the attention of high-level planners. Ease and freedom of access are axiomatic as conditions for receptivity.

Thus far in our report we have concentrated on features associated with the particular technology under consideration. There are several other categories of characteristics that play an important role. The first of these comes under the heading, bureaucratic, and the second, personal, the latter referring to attributes of the individuals who are in a position to make decisions about the introduction of new technologies and methodologies. Most observers of organizational behavior agree that the first law of bureaucracy is to follow the path of least resistance. Hence, anything which threatens to disturb the status quo is likely to be met with overt or covert resistance. Bureaucratic recalcitrance in the face of change is commonplace; the extent and degree of it vary with the kind of innovation being introduced. If, for example, a new piece of equipment has been acquired to do the same old job in virtually the same old way, there is likely to be little opposition. (Note that, due to the factor of human intransigence, there will always be some, as in the case of fireproof clothing and shelters for foresters and, more generally, in the use of seat belts in cars.)

Resistance is especially marked when new technology entails a change in the knowledge level, i.e., when it is accompanied by methods that require new skills, perhaps at a higher level than those previously needed. Where the new technology could perform more "efficiently," i.e., get the work done with fewer people, the level of anxiety and amount of resistance are considerably heightened, especially during a time of high unemployment, such as the present. Almost inevitably, fear of loss of control as new technology and new methods cause shifts in the division of labor constitutes a major barrier to smooth transition. Faced with the danger of being eliminated or becoming atrophied, divisions and departments struggle to survive by whatever means they can muster.

Technological innovation will not find a hospitable environment in the organization (public or private) where the prevailing persuasion is that the agency already possesses the means to accomplish its mission. There must be a positive incentive to change, and usually a perceived need provides that impetus. What we might call the readystate for technological innovation is illustrated by the recent action taken by the California State Resources Water Control Board. Cognizant of its

need to upgrade the monitoring aspect of maintaining water quality, the Board is initiating a full-scale surveillance program utilizing aircraft and camera to check a wide range of conditions affecting water quality. Some of the specific advantages, derived from a pilot project, are listed in the Board's Report as follows:

- An aerial survey team can detect, assess and document pollution incidents, such as oil spills, or incipient problems such as improperly controlled logging operations.
- Remote or relatively inaccessible regions can be inspected effectively by such a team.
- Calls for assistance from regional offices to document severe water quality problems such as fish kills can be handled immediately.
- Through periodic surveillance and photographic documentation, such teams can assist in recognizing trends and rates of change in waterways. A sensitive watershed such as the Lake Tahoe Basin is ideally suited to air surveillance where subtle changes can be identified over the lake's wide surface.
- Aerial surveillance can also help assess progress in the construction of waste treatment facilities funded under the state/federal grant programs.
- It can rapidly assess conditions which may affect water rights applications and permits.
- Finally, such a team can support the public education program by graphically illustrating and documenting pollution problems and solutions*.

It is interesting to note in this respect the number of advantages, attributable to aerial surveillance, that are just as applicable to remote sensing. And, indeed, the authors of the Report acknowledge this likelihood by stating, "None of the more sophisticated methods of remote sensing are considered here, although they make a valuable contribution to a total surveillance program."** They also include specific mention of remote sensing in their list of recommendations, viz. "Future aerial surveillance activities should include an examination of remote sensing technology,"***

*G.W. Fraga and M.E. Holland, "Low Altitude Aerial Surveillance for Water Resources Control," State of California Water Resources Control Board, Publication No. 49, 1973, pp. 1 and 3.

**ibid., p. 1.

***ibid., p. 1.

Seen as the kind of benefits from the proposed surveillance program are the following:

- Rapid screening tool to check discharger self-monitoring reports and identify discharges that require ground-based inspection follow-up.
- Rapid, synoptic overview of a wide variety of water quality problems, and reconnaissance to locate and document unknown discharges and incipient or threatening water quality conditions.
- Aerial patrol over remote or relatively inaccessible regions to provide managers with a broad perspective of conditions in these areas. For example, aerial surveillance has proven effective in the inspection of damaged stream conditions resulting from improperly controlled logging operations.
- Rapid response and wide-ranging freedom of access to problem areas in reporting and in assessing water quality damage resulting from toxic spills, erosion or similar emergent conditions.
- Seasonal, time-lapse photography within sensitive basins to assess significant but long-term changes in land and water related resources. For example, this application is ideally suited to subtle changes taking place in the Lake Tahoe basin.
- Periodic inspections of waste treatment and disposal facilities.
- Orientation of Regional Board staff and basin planners with a balanced areal judgment of complex land and water-related influences.**

Activities of the State and Regional Water Resources Control Boards would, the Report concluded, be considerably aided by the flight service. These are seen to be as follows:

- Waste discharge permits and requirements. Special studies by the Regional Boards assist the establishment of revision of waste discharge permits and requirements by showing potential interactions between dischargers. The relation between a discharge and beneficial use sites is also viewed more readily from the air.
- Self-monitoring report review and checking. Routine surveillance conducted over waste discharge sites subject to self-monitoring provides a rapid assessment of problems that should be reported on the self-monitoring report. It also serves a screening role to identify potential problems for more intensive ground-based checking.
- Waste discharge surveillance. Routine surveillance over waste disposal sites with discharge prohibitions or land disposal gives evidence of actual or incipient pollution problems. Actions to enforce or modify requirements may result from these observations.

- Enforcement. Administrative or legal actions to enforce waste discharge requirements are supported by special flights for photographic evidence. The flights also may be used by the State or Regional Board staff to identify the best sites for ground-level sampling.
- Investigations. Special studies of particular problems or particular areas lend themselves to aerial support for an overview of the conditions and for photographic documentation of selected details.
- Construction grant projects. Special aerial surveys of waste treatment plant construction can assist the planning of ground-level inspections.
- Environmental assessments. Special flights allow State Board personnel to identify significant factors that should be included in the review or preparation of environmental impact reports.
- Basin planning. The synoptic overview is of particular value in orienting basin planners to regional conditions. Special study flights for both State and Regional Board personnel are used.
- Surveillance system design. The effort in developing a comprehensive monitoring and surveillance system benefits from special study flights in selected areas to identify existing and potential sampling sites.
- Research. Special study flights support research and development studies involving significant field work. The tracing of dye releases and the selection of detailed field study sites are particularly suited to aerial support. The development of remote sensing and aerial surveillance methods specifically useful to the State and Regional Boards also draws on the operational aerial surveillance program.
- Appropriative water rights. Special flights over proposed water diversion sites establish relations to other water uses or areas of significance. The progress of work in relation to diversion permit provisions is also subject to aerial assessment.
- Water rights adjudications. Special studies of streams that are involved in adjudications benefit from the synoptic view of the stream system and relative locations of diverters.*

* Ibid., p. 37-38.

The specific program objectives set forward coincide remarkably with those which might be anticipated for a similar remote sensing effort at some time in the not too distant future:

Program Objectives

The objective of the aerial surveillance program is to support the activities of the State and Regional Boards and assist them to make more effective use of their limited staff resources. Specific objectives include:

- Provide periodic, synoptic overview of water quality conditions, waste treatment facilities, and disposal areas throughout the State as part of the monitoring-surveillance activity contained in Basin Water Quality Control Plans.
- For visible water quality factors and pollutants, check conditions in the discharge area against discharger self-monitoring report results.
- Provide detection, documentation, and interpretation of water quality conditions for the support of State and Regional Boards' activities.
- Detect, assess and document pollution incidents, emergent water quality problems, and threatening conditions.
- Develop photographic inventories of water quality conditions, waste treatment facilities, and threatening watershed conditions for comparison with later conditions to identify rates of change and trends.
- Provide periodic aerial assessment of progress in facility construction and the reporting of possible threat to the local environment.*

It is certain that, with needs so clearly identified and defined, the Board's project will encounter little resistance on the part of operating agencies. Some of the most beneficial effects will, in fact, add a capability through the synoptic view, to attain and maintain quality standards hitherto beyond reach, without perturbing existing operations. Perhaps the step toward aerial surveillance may be considered intermediate, -- a necessary link between ground-based methods and remote sensing techniques. One of the interesting lessons to be derived from this innovative step taken by the California State Water Resources Control Board is that perception of need is a vital ingredient of receptivity toward new information sources. When this perception is coupled with an understanding of the techniques associated with utilizing the data, the transfer process is considerably eased. Cognizant of these relationships

*Ibid., p. 38

between (1) need, (2) understanding of the techniques, and (3) receptivity, the researchers associated with the Integrated Project devote considerable time and energy to what might be called "missionary work", i.e., sensitizing managers to their needs and acquainting them with the technical means through which they may be served.

5.2.2. Benefit-Cost Analysis as a Tool in Evaluation

Earlier in this report, we mentioned that one focal point in our research is the way government agencies evaluate innovations. So prevalent among the methods employed is benefit-cost analysis that special sections, prepared by experts on the subject, have been included in foregoing Progress Reports to provide background information and review.* In the 1 May, 1974 Report, Professor Leonard Merewitz provided views "On the Feasibility of Benefit-Cost Analysis Applied to Remote Sensing Projects". Consistent with Mason's caveats and Merewitz's recommendations, our own work on cost-effectiveness** progresses, as is shown elsewhere in this Progress Report. As has been noted, members of the Social Sciences Group have developed, in concert with remote-sensing specialists and statisticians, demonstrations in assessing the cost-effectiveness of specific uses of remote sensing for certain operations germane to water management. We shall in the future continue to develop further studies of this kind so that decision-makers will have a substantive and well-documented base on which to make their choices and plans.

In addition, we continue to study the uses and abuses of benefit-cost analyses as a means of arriving at public policy decisions because this is the prevailing approach to policy and program evaluation in practically every sector of government and at every level. Interesting to note, this method of assessment had its origin in water management. The Flood Control Act of 1936 was the first step taken by the federal government to initiate river and watershed improvements "if the benefits to whomsoever they may accrue are in excess of the estimated costs".*** Through this legislation, the Secretary of the Interior was required to estimate the total benefits and total costs of every project. The sum of the benefits from a proposed project was supposed at least to cover total project costs if Congressional authorization was to be secured. Originally applied only to the Army Corps of Engineers and to the Department of Agriculture, the dictum embodied in the Flood Control Act of 1936 was subsequently accepted by many federal agencies as a basis for determining the economic feasibility

*Richard O. Mason, "Beyond Benefits and Costs: A Study of Methods for Evaluating the NASA-ERTS Program", Space Sciences Laboratory, U.C. Berkeley (Internal Working Paper Series).

*Leonard Merewitz, "On the Feasibility of Benefit-Cost Analysis Applied to Remote Sensing Projects", Special Study No. 1. Semi-Annual Progress Report, 31 Dec. 1973.

**This method of evaluation has advantages, in a decision tableau, over benefit-cost analysis, in that it does not depend exclusively on numerical estimates of either costs or benefits and allows for a broader conception than that which accommodates only immediately available figures.

*** U.S. Statutes-at-Large 1510 (1936).

of projects. 1946 marked the establishment of the Subcommittee on Benefits and Costs to the Federal Inter-Agency River Basin Committee and their report * became the accepted statement of principles. As time has gone on and experience with the techniques has accumulated, economists have become increasingly critical of the apparent manipulation of benefit-cost analysis because of the likelihood that calculations are not sufficiently rigorous, data not unequivocally accurate, and advocacy not altogether absent. For example, studies * of the Bureau of Reclamation suggest that an overstatement of benefits and understatement of costs have led to construction of projects that would not have appeared feasible if other evaluative procedures had been applied.

Specifically, the Bureau's procedures for benefit-cost analysis were seen to be deficient because they (1) omit opportunity costs of the water diverted for project purposes; (2) improperly include secondary benefits; (3) employ low discount rates; and (4) exaggerate primary benefits through the farm budget procedures by valuing farm output on the basis of support prices, by not accounting for the effects of variability in the supply of project water, and by not properly evaluating the opportunity costs of farm-investor and owner-operator labor.**

Because benefit-cost analysis is the prescribed and approved method whereby Congress and Federal agencies arrive at decisions about water resources projects, the Comptroller General made a special review of the methods and procedures employed by a number of departments for projects which included flood control, irrigation, power, recreation, fish and wildlife enhancement, and municipal and industrial water supply. Covered by the investigation were the Bureau of Reclamation of the Department of the Interior, Army Corps of Engineers, Soil Conservation Service of the Department of Agriculture, and the Tennessee Valley Authority Service projects. All were subjected to scrutiny -- three Corps, two Bureau, one Soil Conservation Service, and one T.V.A. In the Report to Congress,*** the GAO made a number of criticisms that should serve as caveats and as useful guidelines since they pertain directly to management of water resources and because the shortcomings underscored in the Comptroller General's overview are so widespread and so often neglected in benefit-cost calculations about water. A number of specific criticisms were made: (a) There were numerous

*e.g., Otto Eckstein, Water Resource Development: The Economics of Project Evaluation, Cambridge, Mass., Harvard University Press, 1958.

J. Hirshleifer, J. De Haven, and J. Millman, Water Supply: Economics, Technology, and Policy, University of Chicago Press, Chicago, Illinois, 1960.

N. McKean, Efficiency in Government through Systems Analysis: With Emphasis on Water Development, New York, John Wiley, 1958.

**For full discussion of the Bureau of Reclamation's use of cost-benefit analysis see: Steve H. Hanke and Richard A. Walker, "Benefit-Cost Reconsidered: An Evaluation of the Mid-State Project," Water Resources Research, Vol. 10, No. 5, October, 1974, pp. 898-908.

***Comptroller General of the United States, Report to the Congress, "Improvements Needed In Making Benefit-cost Analyses for Federal Water Resources Projects", B-167941, September, 1974.

instances of inconsistency in computing benefits. For example, along with benefit values for flood control protection to existing property, flood control benefit calculations included values for normal growth in some cases, induced growth in others, and neither in still others. (b) Benefits were not based on analysis of conditions with and without the project. In fact, a major portion of flood control benefits claimed for six out of the seven projects used a "systems" instead of an "incremental" approach. Thus, the benefits were accumulated for all projects in a river basin and then distributed to the projects in proportion to each one's flood control capability. The result was an understatement of the benefits for projects installed first and an overstatement for those to come last. The dollar difference with respect to the Grand River Basin came to over one million dollars, when the systems and the incremental methods were contrasted.* (c) Benefit computations were not adequately supported. Lack of documentation and failure to perform detailed study to substantiate claims were stressed in a number of cases. In one instance, when an estimate was not supported by a study, a TVA official stated that "the benefits were too trivial to warrant an expensive supporting study to replace a reasonable assumption." GAO's position: "We believe...that when benefits were considered important enough to claim they should have been adequately supported!"** (d) Project costs and induced costs were not fully considered in the benefit-cost determinations. Noted in the computations about the TVA Duck River project were various important oversights, such, for example, as adverse effects of industrial expansion and related growth which would increase water needs and quantities of raw wastes requiring treatment. While TVA had computed hunting and habitat losses from inundation, similar effects resulting from land development around the project reservoirs received no notice.

The following were listed as causes of the problems in the benefit-cost determinations: (1) generalized and incomplete agency guidance and instructions; (2) varying interpretations and inconsistent application of Senate Document 97 criteria and agency implementing procedures; (3) lack of or incomplete studies and analyses by the agencies of data pertinent to making determinations and computations; (4) inappropriate or questionable assumptions for making benefit computations.***

Because the Social Sciences Group is concerned with the methods which public agencies apply in their evaluations of new proposals, projects, and procedures, we regard this aspect of our ongoing research as especially important and we often serve in an advisory capacity when benefit-cost studies are being utilized in the decision-making process. In this capacity, we have been able to serve various state and federal agencies who have sought advice in the socio-economic aspect of the particular project at hand.

*Ibid., p. 24.

**Ibid., p. 32.

***Ibid., p. ii.

5.3 Plans and Prospects

Our studies of the socio-economic aspects, impacts, and implications of water resource decisions will be considerably strengthened by an internal reorganization that has augmented the professional staff of the Social Sciences Group. Mr. James M. Sharp became a permanent member after having worked on a consulting and liaison basis with the remote sensing group. A resource economist, he will continue his joint studies on the cost-effectiveness of various applications of remote sensing and will pursue avenues of research based on his interests within the framework of the Social Sciences Group. Subsequent reports will reflect this orientation, which is consistent with the guidelines set forth by Dr. Peter Castruccio.* While details have still to be clarified, we are also planning a joint study with Dr. Jack Estes and the Santa Barbara group on socio-economic aspects of their remote sensing work.

We shall continue our study of the evaluation criteria utilized in project planning and in public decision-making. In this connection, we will focus on benefit-cost analyses and environmental impact statements, with a view to ascertaining the qualifications of the analysts, the adequacy and source of the data base, the appropriateness of techniques used, and the ways in which intangibles are taken into account. Not unrelated to this area of study is the inquiry into projection technologies now in use in resource management. The information base, the built-in assumptions, and the interpretations are crucial ingredients of the methods and require close scrutiny through the broad lens of the social sciences as well as the narrower lens of the technical specialist.

We expect to carry further our investigation of the relation of the management of California water resources to (1) the management of other resources, especially land; (2) other public agencies; (3) other levels of government, i.e., local, federal. It is with relation to the latter that we shall be particularly concerned since here is the historical battleground where conflicting notions of sovereignty clash. At present, the issue appears to be environmental protection and there are many unresolved problems as to rights, responsibilities, and regulatory powers.

Another matter of tremendous importance has to do with public participation in the decision-making process. Our contacts with high-level officials in water management have convinced us that this is an area of primary concern in an era when consumerism, conservation, and environmental protection are becoming factors in policy formulation and yet are elusive and unpredictable. How to elicit involvement on the part of the public and yet avoid the pressures of special interests and disruptive tactics of vade mecum** activists ready to ride any cause to suit their own purposes is a problem facing and puzzling administrators at all levels of government and whether their main responsibility be energy, water, land, or any other resource.

*Letter from Arthur G. Anderson, (Chairman of the Committee) to Dr. Gordon J.F. MacDonald (Chairman, Commission on Natural Resources), August 5, 1974.

**Latin for "go with me."

The final item on our agenda for the future has to do with socio-economic issues bearing on the water-energy relationship. These must be recognized and studied even though they do not lend themselves to rigorous analysis and experimentation. Our preliminary literature search has revealed that much intellectual energy has been directed to the paucity of research and neglect of the political, social, and economic aspects of the water-energy relationship. The nostrum usually prescribed is "comprehensive social analysis" but this remains too nebulous to be useful. This is an area that becomes even more urgent, however, as society ponders its future and tries to develop ways of planning consistent with the total spectrum of realities -- the limitations, the constraints, -- ultimately toward attaining and maintaining a better quality of life.

Additional activities of the Social Sciences Group are reported in Chapter VI and are reflected in Special Study 5.

CHAPTER 6

A COMPARATIVE COST-EFFECTIVENESS ANALYSIS OF EXISTING AND LANDSAT-AIDED SYSTEMS FOR ESTIMATING SNOW WATER CONTENT

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TABLE OF CONTENTS

	<u>Page</u>
6.100 Introduction	6-1
6.200 Cost-Effectiveness Analysis	6-2
6.300 Current Snow Survey Activities	6-6
6.310 Production Process	6-6
6.320 CCSS Budget	6-10
6.330 Extent of Surveys	6-11
6.340 Cost of Surveys	6-13
6.350 Accuracy of Surveys	6-16
6.400 Comparative Analysis	6-20
6.410 Difficulties of Comparison	6-20
6.420 Sources of Error	6-22
6.430 Comparative Sampling Design	6-23
6.431 The LANDSAT-Aided System	6-23
6.432 The Current CCSS System	6-30
6.440 Performance Comparison	6-31
6.441 Unit Costs	6-32
6.442 Sample Size	6-32
6.443 Precision	6-37
6.500 Conclusion	6-40
6.510 Summary	6-40
6.520 Major Conclusions	6-41
6.521 Cost Savings	6-41
6.522 Increased Precision	6-41
6.523 Additional Abilities	6-42
6.530 Major Recommendations	6-43
6.531 Modeling and Testing Process	6-43
6.532 Evaluation and Implementation Process	6-44
6.600 References	6-45
Appendix I - Sample Size Determination for Watershed Snow Water Content Estimation Utilizing Stratified Double Sampling with Regression Estimation	6-47
Appendix II - Statistics Used in the Calculation of Sample Sizes and Allowable Errors for the Remote Sensing-Aided Snow Water Content Estimation System	6-57
Appendix III - Determination of Allowable Error for CCSS Snow Course Data	6-60

A COMPARATIVE COST-EFFECTIVENESS ANALYSIS OF EXISTING AND LANDSAT-AIDED SYSTEMS FOR ESTIMATING SNOW WATER CONTENT

6.100 INTRODUCTION

Problems in managing natural resources often reduce to problems in allocating scarce time and money resources. Technological innovations like LANDSAT, by dramatically reducing the costs of gathering information promise to beneficially alter existing time, cost, and capability relationships in many resource management areas. But the path from promise to realization can be a long one, requiring among other things the development of an adequate analytical framework for comparing new and established technologies.

This chapter describes and applies a methodology for comparing different information-gathering technologies. Although the focus here is on a particular resource (water) in a particular context (snow mapping and runoff prediction) over a particular region (the Feather River Watershed of Northern California), the approach can be generalized to cover other natural resource data acquisition situations. It is shown below, moreover, that the theory behind the methodology is far less novel than its application to a resources information problem.

The overriding objective for the work described in this section was stated in our May 1974 annual progress report: "To determine if remote sensing can be cost-effectively integrated with data presently used in the California Cooperative Snow Surveys (volumetric) model to produce potentially more precise and accurate estimates of water supply." (emphasis added).

Attention in this study is directed toward the estimation of snow water content, a major predictor variable and intermediate output of this California Cooperative Snow Surveys (CCSS) volumetric yield prediction model. Normally, snow water content estimates are developed directly from ground-based snow course measurements. Instead, this study introduces a stratified double sampling approach that relates the ground-based estimates to snow areal extent data gathered from LANDSAT-1 imagery. The resulting relationships enable low-cost remotely-sensed data to account for a large portion of basin snow water content variability.

Although at this stage we can draw only tentative and partial conclusions with respect to our foregoing objective, the potential of remote sensing for aiding in the snow water estimation process appears to be very great indeed. So far we have focused mainly on the cost and capability parameters involved in the existing methods of water supply estimation. Those portions of the CCSS volumetric model dealing with snow water content

estimation are isolated for comparison with the LANDSAT-aided model. Preliminary cost and accuracy estimates for snow water content have been developed for both models. The two sets of estimates still require additional refinement and augmentation before our tentative conclusions can be verified. Nevertheless, the favorable interim results encourage us to continue our efforts to integrate remotely-sensed information with existing yield models on a test basis.

This chapter summarizes progress to date in a format that blends economic and statistical theory with an operational situation. An initial section briefly describes cost-effectiveness analysis and how it can be used. A following five-part section documents various aspects of the hydrologic modeling methodology now carried on by the Snow Surveys and Water Supply Forecasting Branch of the California Department of Water Resources: their production process, their budget, and the extent, cost and accuracy of their snow surveys. A third section demonstrates the cost-effectiveness methodology by comparing the sample designs and performance of the existing and LANDSAT-aided snow water content measurement approaches. A final section summarizes the research and discusses conclusions and recommendations for future work.

6.200 COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis is one of several techniques that attempt to apply economic rationality to public investment decision making. Benefit-cost analysis is its closest theoretical relative, although techniques used in systems analysis, operations analysis, planning, programming and budgeting systems (PPBS), and others bear strong resemblance to the cost-effectiveness approach. These techniques all share a common purpose: i.e., to make systematic and quantitative comparisons between alternative resource allocation options, using a logical sequence of steps that can be verified by others.

Traditional resource allocation processes have been a mixture of political, administrative, and professional judgement. Their purpose is typically to find a pattern of production which is most efficient, or lowest cost for a set of desired outputs. Without a price mechanism to allocate output, some other procedure is necessary.

Historically, the new resource allocation techniques developed following World War II as public expenditures grew and oligopolies proliferated in the private sector. The lack of classical market forces in the public sector generated the need for developing alternative approaches to use in guiding government investment decisions. Benefit-cost analysis helped fill that need by supplying an investment project appraisal method closely analogous to that used by businessmen. The major difference is that estimates of social value are used in place of sales value (or profitability) estimates. Benefit-cost analysis techniques were applied first to physical investments like military procurements and water resources projects. By the 1960's these techniques had been refined and extended to human investments such as manpower training and outdoor recreation. More recently, the techniques have found application in government research and development programs and information services like LANDSAT.

The choice of appraisal methodology depends upon the nature of the investment and the information available. Both benefit-cost and cost-effectiveness analyses contain their own variants, advantages, and limitations. In benefit-cost analysis, every effort is made to quantify in commensurable monetary terms both the benefits and costs stemming from alternative actions. Physical outputs are projected, social values (positive and negative) are estimated for these outputs, and benefits and costs are compared over time, either on a gross annual basis or on a net benefit basis discounted to the present. A complete analysis includes not just immediate benefits and costs to the agency and its clients, but also the spillover benefits and costs to others not directly related to the action in question. The result is a ratio of benefits to costs for each alternative action considered.

Cost-effectiveness analysis, in contrast, allows the use of multiple, non-commensurable measures on the benefit side. Economic benefits are stated in terms of cost savings. The method is specifically directed toward problems in which outputs cannot be evaluated in market prices, but where inputs can, and where the inputs are substitutable at market-developed exchange relationships. Cost-effectiveness analysis thus helps a decision-maker answer questions about how to achieve a given set of objectives at the least cost, or how to obtain the most effectiveness from a given set of resources.

Some kind of cost-effectiveness analysis is involved in any decision concerning resource allocation. In the usual case, a decision-maker relates the costs of alternative scarce resources (inputs) to specified performance standards (outputs) desired from a production process. The decision-maker may be looking for the least expensive way to meet the specifications or for a means of adjusting the specifications to fit a fixed budget. In either case, the decision-maker seeks to establish cost-capability relationships for various combinations of resource alternatives.

Several variants of cost-effectiveness analysis may be distinguished. One type, known in defense circles as a "system configuration study," emphasizes the selection of a particular configuration of system characteristics which will achieve various performance levels at a minimum cost or, conversely, the identification of achievable characteristics which will maximize performance within various funding levels. Such an analysis might be useful, for example, in selecting between various range, speed, and weight characteristics of aircraft with different costs and payloads.

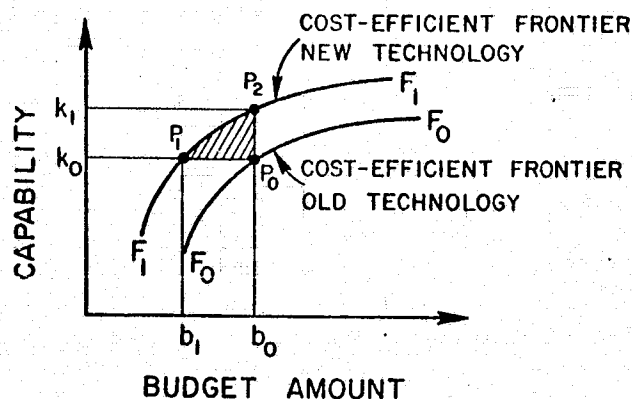
A second type of cost-effectiveness analysis, known as a "force structure study," relates costs and effectiveness of alternative packages of options over time. Also extensively used by military planners, this variety of analysis helps identify the optimum force mix of a phased program like a weapons system through a planning and budgeting period of several years.

A third type of analysis, called a "system comparison study," emphasizes the comparison of two or more systems for the same mission. Here the focus is on intersystem analysis, rather than the intrasystem approach used in system configuration studies. It is presumed that competing systems already have been optimized as to their internal configurations. It is also presumed that these systems satisfy approximately the same organizational objectives. By examining side-by-side the cost-capability relationships of the competing systems, a decision-maker can assess the marginal improvement promised by alternative systems either in cost savings at various effectiveness levels or in maximum effectiveness at given budget levels. When compared with the other two types of cost-effectiveness studies, the system comparison approach has two distinct advantages:

- (1) costs are generally required in less detail, and
- (2) the spread of costs over time is usually deemphasized or ignored.

The system comparison type of cost-effectiveness analysis is well-suited for identifying the potential contribution of new technologies to the cost-capability relationships of existing systems. Figure 6.1 illustrates the effect of technological progress on the cost-capability "frontier" of an existing production system. The frontier F_0F_0 shows the maximum capability that can be expected from the present system at a given level of budget. A system producing on the frontier is defined as "cost-effective" because a decrease in cost is not possible without a decrease in capability. A technological advance would beneficially alter this relationship: the cost-efficient frontier would be pushed out to some new set of points F_1F_1 . A point P_0 on the old frontier F_0F_0 would now represent an inefficient pattern of production. A set of points in the shaded area of Figure 6.1 would represent an improved

FIGURE 6.1 - EFFECT OF A TECHNOLOGICAL ADVANCE ON A COST-CAPABILITY PRODUCTION FRONTIER



return, with cost-efficient points now lying on F_1F_1 between P_1 and P_2 . The effect of technological progress thus ranges between equivalent capability at a lower budget (P_1) and greater capability within the same budgetary constraints (P_2).

The foregoing model is used later in section 6.400 for assessing the effect that LANDSAT imagery could have on current snow water content estimation procedures in California. The comparative cost-effectiveness framework, because it deemphasizes the quantification of benefits, is more adapted to this current stage of work than the typically more ambitious benefit-cost analysis. An identification and evaluation of the benefits stemming from improved hydrologic modeling will be part of future work.

Anyone applying the foregoing investment appraisal techniques should be aware of their potential limitations. Many limitations are related to problems inherent in measurement. Time and money costs ordinarily curtail the extent of measurements that can be undertaken. In addition, certain considerations may be too intangible or subject to too much uncertainty to be measured accurately. Costs may or may not be amenable to precise measurement, while measures of effectiveness are necessarily approximations of a system's ability to achieve certain objectives. Other limitations are related to problems of choice. Human judgement and subjectivity permeate most analyses. Advocates of a particular "party line" regarding a project can often bias the analysis in their favor with a judicious selection of assumptions and relevant factors. A final caveat is that the analytical techniques by themselves are insufficient for informed decision making. Benefit-cost analysis rarely helps with distributional or broad value questions, and cost-effectiveness analysis offers little assistance in guiding the selection of appropriate system-wide objectives.

Most of the shortcomings inherent in public investment appraisal techniques can be reduced by employing a careful research design. Measurement, choice, and insufficiency limitations can all be minimized by placing a problem in its proper context. In the case of a public agency, this usually involves examining and documenting relevant aspects of the organization's structure and performance. Such research can aid in narrowing uncertainty boundaries, in formulating explicit assumptions, and in clarifying organizational objectives. A well-documented qualitative analysis can greatly enhance the reliability and verifiability of a quantitative comparison between investment alternatives.

6.300 CURRENT SNOW SURVEY ACTIVITIES

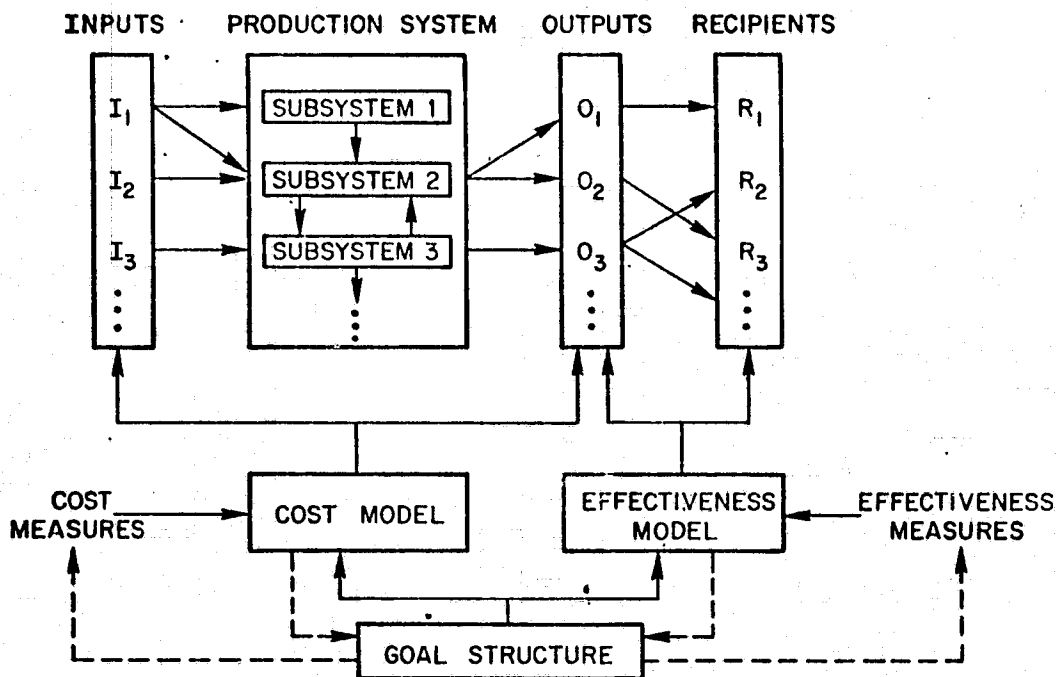
Understanding a problem's context often can be the major part of analyzing and solving the problem itself. Context is especially important in resources information problems that involve determinations about the value of data, information, and decisions. This section documents the qualitative and quantitative context relevant to our cost-effectiveness investigation of snow survey and water supply forecasting activities within the California Department of Water Resources.

6.310 Production Process

Since 1929, the Department of Water Resources (DWR) has coordinated California's program of snow surveys and water supply forecasting. The stated objective of this program is to "reliably predict the State's snow-melt runoff as necessary to meet the annual operating needs of California's water using agencies." The program's product is the water supply forecast. Forecasts are published in DWR Bulletin 120 titled "Water Conditions in California" and issued five times a year. Four reports contain water supply forecasts based on snow conditions as of the beginning of February, March, April and May, respectively. The fifth report is distributed in December and summarizes the previous water year.

DWR water supply forecasts can best be viewed in context with the entire program of snow survey and water supply forecasting activities. Using a systems analysis perspective, the program can be seen as a production process that transforms a variety of inputs into specified outputs. Figure 6.2 portrays this process in a schematic model. The model is sufficiently general to apply to other classes of public services. It represents a structure in which resources of different types (I) are transformed into quantities of outputs (O) and delivered to various groups of recipients (R). The nature of the transformation process is determined by the relative cost of inputs and their substitution possibilities as well as the technical, organizational, and institutional relationships within the production subsystems. The relative quantities of outputs produced and their distribution among recipients depends upon the form of allocation procedure adopted.

FIGURE 6.2 - SCHEMATIC MODEL OF A PUBLIC SERVICES PRODUCTION SYSTEM



The upper portion of Figure 6.2 diagrams the structure of a public services production system. The lower portion of Figure 6.2 outlines how the performance of such a system could be evaluated using a cost-effectiveness approach. For alternative output configurations, the cost model determines the total cost of producing outputs under the assumed system structure and production relationships. The effectiveness model, on the other hand, relates output characteristics to the achievement of system objectives which include satisfying the needs of recipient groups. Measuring costs and effectiveness is not an easy task, as discussed previously, but the measurement process can be simplified if the system's goal structure has incorporated standards that are output-oriented and operational on a system-wide basis.

Our research concerning the DWR snow survey and water supply forecasting activities can be conveniently described in terms of the Figure 6.2 generalized production model. On the input side, we discovered that three classes of resources are used in the snow survey and water supply forecasting production process: (1) personnel and services, (2) materials and equipment, and (3) financial support. These resources are provided by the DWR and around 50 cooperating agencies, or "cooperators." Within the California Cooperative Snow Surveys (CCSS) program four types of cooperators can be identified using unofficial classifications:

- contractor-cooperators, such as the U.S. Forest Service and U.S. Park Service, that provide services and equipment to the CCSS program on a contractual basis;
- "fixed-funding" contributor-cooperators, such as certain water and irrigation districts, that contribute a flat fee to the program each year;
- "variable-funding" contributor-cooperators, such as certain private organizations and water associations, that contribute a varying fee each year depending on the direct costs of snow survey work on their water supply; and
- "services and funding" contributor-cooperators, such as cities and power companies, that provide services and equipment in addition to financial contributions.

Table 6.1 lists the cooperators that participated in the 1974 snow surveys program.

Examination of the DWR snow survey and water supply forecasting production system reveals that information gathered through the CCSS program is just one of several information sources. Snow survey data (regarding snow depth and water content) are combined with data on precipitation, runoff, and water storage in major reservoirs. The resulting information is fed into water-yield algorithms and analyzed by the DWR staff to produce regularly-updated forecasts of water supply.

TABLE 6.1 - AGENCIES PARTICIPATING IN THE 1974 CALIFORNIA COOPERATIVE
SNOW SURVEY PROGRAM

Public Agencies

Buena Vista Water Storage District
Central California Irrigation District
East Bay Municipal Utility District
Friant Water Users Association
Kaweah Delta Water Conservation District
Kaweah River Association
Kings River Water Association
Los Angeles County Flood Control District
Lower Tule River Irrigation District
Merced Irrigation District
Modesto Irrigation District
Nevada Irrigation District
Oakdale Irrigation District
Omochumne-Hartnell Water District
Oroville-Wyandotte Irrigation District
Placer County Water Agency
Porterville Irrigation District
Sacramento Municipal Utility District
Saucelito Irrigation District
South San Joaquin Irrigation District
St. Johns River Association
Tule River Association
Turlock Irrigation District
Vandalia Irrigation District
Yuba County Water Agency

Private Organizations

Atmospherics Incorporated
J. G. Boswell Company
Kern County Land Company
Liberty Farms Company
Mt. Reba Inc.
Union Carbide Corporation

Public Utilities

Pacific Gas and Electric Company
Sierra Pacific Power Company
Southern California Edison Company

Municipalities

City of Los Angeles
Department of Water and Power
City of Porterville
City and County of San Francisco
Public Utilities Commission

State and Federal Agencies

California Department of Water Resources
California Department of Parks and Recreation
U.S. Department of Agriculture
Forest Service (14 National Forests)
Pacific Southwest Forest and Range Experiment Station
Soil Conservation Service
U.S. Department of Commerce
National Weather Service
U.S. Department of the Interior
Bureau of Reclamation
Geological Survey, Water Resources Division
National Park Service (3 National Parks)
U.S. Department of the Army
Corps of Engineers

Other Cooperative Programs

Nevada Cooperative Snow Surveys
Oregon Cooperative Snow Surveys

Source: California DWR Bulletin 120-74 (May 1974).

The forecasts appear formally in the DWR-prepared Bulletin 120. Most of the non-snow survey data are supplied by the U.S. Forest Service, dam operators, and other divisions of the DWR. Activities within the snow surveys production subsystem are coordinated and scheduled by the DWR staff. The DWR also helps by providing occasional safety and training sessions for snow survey crew members, by setting up and maintaining the snow courses, survey equipment, and supply stations, and by providing field and technical assistance as required to meet the forecasting needs of cooperating agencies. Non-DWR cooperators contribute the remaining manpower and perform a majority of the measurements.

The major output of this process has already been described. In any given year, the first four issues of Bulletin 120 are sent to subscribers within ten days after snow conditions have been reported on the first of February, March, April and May, respectively. A fifth issue, containing the October-September water year summary is published in December. The reports contain water runoff forecasts for 20 California watersheds in which snowmelt constitutes a significant portion of the yearly water yield total. In addition, snowpack, precipitation, runoff, and reservoir storage summaries for seven hydrographic areas also appear in these reports. Specialized estimates and forecasts constitute an important secondary output. The DWR forecasting personnel furnish these additional services as requested and required by specific water management groups.

As the primary recipients of the runoff forecasting output, cooperating agencies are better equipped to make decisions about conserving available water supplies. The forecasting information also reaches many other subsidiary agencies, agriculturalists, and institutional groups that are not regular snow survey cooperators.

6.320 CCSS Budget

An agency's budget provides an obvious starting point for evaluating the cost of outputs produced. In the case of the snow survey and water supply forecasting activities of the DWR, we found that the entire production process has been running on an "official" annual budget of around \$300,000. About 90 percent of this amount comes from State general fund support. The remainder, about \$30,000 a year, consists of reimbursements from CCSS program cooperators.

The DWR snow surveys group has estimated that cooperators contribute services far in excess of their reimbursements. This occurs because many cooperators absorb the state survey costs along with their own snow survey efforts. The DWR estimates (very roughly) the value of these unaccounted services at around \$200,000 per year. This implies an "unofficial" snow survey annual budget in the neighborhood of \$500,000.

Table 6.2 shows the official version of cooperative snow survey program requirements over a ten-year span. General fund support and reimbursements from cooperators appear as actual figures for years 1966/67

through 1973/74, as estimates in 1974/75, and as projections for 1975/76. General fund entries are more reliable than the reimbursement figures.

These annual budgets represent a fairly level commitment over the years in terms of DWR personnel. The 1974/75 budget calls for 7 full-time positions, 4 temporary positions, and 1 consultant. Total salaries plus a 67 percent overhead factor equal about \$225,000, or nearly 80 percent of the snow survey budget.

Program costs within the budget are allocated about 50:50 between survey support and forecast activities. The DWR's non-salary direct costs for snow survey activities in 1974/75 are budgeted at around \$28,000. This includes \$19,000 for contractors, \$4,000 for flying services and other support, and \$5,000 for sensor equipment. These costs are expected to be fully offset by contributions from cooperators. Budgets in future years are likely to contain greater outlays for sensor equipment as automatic sensors and other sophisticated measurement devices are brought into use.

6.330 Extent of Surveys

Our comparative cost-effectiveness methodology requires that competing systems satisfy approximately equivalent objectives. An analysis of snow survey efforts was thus required to establish an adequate basis of comparison. We approached this task by asking a familiar set of questions: what? where? when? who? and how much?

TABLE 6.2 - STATE BUDGET FOR COOPERATIVE SNOW SURVEYS, 1966/67 - 1975/76

YEAR	GENERAL FUND SUPPORT	REIMBURSEMENTS FROM COOPERATORS	TOTAL
1975/76 (Proposed)	\$ 285,000	\$ 35,000	\$ 320,000
1974/75 (Estimated)	253,557	30,835	284,392
1973/74	250,537	68,427	318,964
1972/73	258,552	29,697	288,249
1971/72	242,883	24,487	267,370
1970/71	242,351	17,585	259,936
1969/70	223,880	29,250	253,130
1968/69	191,693		191,693
1967/68	179,180	6,600	185,780
1966/67	183,410	4,800	188,210

SOURCE STATE OF CALIFORNIA BUDGET (1968/69-1974/75) AND
"COOPERATIVE SNOW SURVEYS PROGRAM COMPONENT"
STATEMENT, BUDGET ADDENDUM, 12 JULY 1974.

California's cooperative snow survey program uses three basic means of collecting snow data: the snow measurement course, the aerial snow depth marker, and the automatic snow sensor. Snow depth and water content measurements at some 320 snow courses are the CCSS program's primary source of data. Most courses contain a standard of 10 sample points, usually spaced at 50 or 100 foot intervals, along an established line or configuration. Snow courses are typically located in meadows to avoid extremes of wind, snow accumulation, and ponding. Annual measurements in the same locations provide an index to snow cover for forecasting basin runoff. Aerial markers provide supplementary snow depth information. These marked, vertical poles are frequently placed near snow courses and are usually observed from low-flying aircraft. In the 1974 snow season, 374 observations were made at 160 aerial marker sites. Automatic snow sensors are now being used on an experimental basis at 40 remote sites. These facilitate frequent monitoring and updating of water supply forecasts and are likely to be used more in the future.

Snow survey measurements are performed in 37 river basins lying within 5 hydrographic areas. Since our LANDSAT-aided snow aerial extent information is specific to the Feather River Basin, we were especially interested in knowing more about the snow survey work there and how it compared with the rest of the state. Table 6.3 summarizes the results of our inquiry. It shows for 1970 and 1974 the number of active aerial

TABLE 6.3 - COMPARISON OF SNOW SURVEY EFFORT BY SURVEY TYPE, 1970 AND 1974, FEATHER RIVER BASIN AND ALL STATE BASINS

AERIAL MARKERS				SNOW COURSES			
	NUMBER ACTIVE	NUMBER OF VISITS	VISITS PER MARKER	NUMBER ACTIVE	NUMBER OF VISITS	VISITS PER COURSE	
FEATHER RIVER BASIN	1970	8	24	3.0	26	84	3.2
	1974	9	3	.3	29	125	4.3
	CHANGE	+12%	-88%		+12%	+49%	
ALL STATE BASINS	1970	152	486	3.2	315	864	2.7
	1974	160	374	2.3	323	1014	3.1
	CHANGE	+ 5 %	- 23 %		+ 3 %	+ 17 %	
RATIO:							
FEATHER R STATE	1974	6%	1%	9%	12%		

SOURCE: CALIFORNIA DWR BULLETINS 129-70 (SEPTEMBER 1971)
AND 120-74 (MAY 1974).

markers and snow courses and the number of measurement visits made to these sites in both the Feather River Basin and throughout the state. The table also shows for both areas the percentage change in survey effort since 1970. A decline in aerial marker surveys appears to be compensated by additional snow course visits. The bottom of Table 6.3 shows the survey effort in the Feather River Basin as a percentage of total 1974 aerial marker and snow course survey work.

We also asked which cooperators were performing which surveys. The results for snow course visits are summarized in Table 6.4. We found that the Pacific Gas & Electric Company performed about half of the Feather River Basin snow course measurement activity in 1974. DWR personnel performed another third of the measurements. We estimated that the total 1974 survey effort in the Feather River Basin took about 60 days of cooperator time.

6.340 Cost of Surveys

The diagram in Figure 6.2 portrayed how a "cost model" can relate the inputs and outputs of a public services production process. Such apparent theoretical simplicity often obscures a multitude of practical application difficulties. Our cooperative snow survey example is a case in point. Again, the major problem was one of comparison: we had

TABLE 6.4 - COMPARISON OF SNOW SURVEY EFFORT BY COOPERATORS, 1970 AND 1974, FEATHER RIVER BASIN AND ALL STATE BASINS

COOPERATOR	PORTION OF TOTAL SNOW COURSE VISITS PERFORMED BY COOPERATOR		
	ALL STATE BASINS	FEATHER RIVER BASIN	
	1970	1970	1974
US FOREST SVC RANGER DISTRICTS	30 %	11 %	9 %
DWR	16	40	33
PACIFIC GAS AND ELECTRIC CO	14	39	50
NEVADA COOPERATIVE SNOW SURVEYS	13	0	0
OTHER COOPERATORS	27	10	8
TOTAL	100 %	100 %	100 %

SOURCE CALIFORNIA DWR BULLETINS 129-70 (SEPTEMBER 1971) AND 120-74 (MAY 1974), AND SNOW SURVEY INDEX AND MEASUREMENT SCHEDULE 1974.

to isolate the costs of those snow survey subsystems that produce outputs comparable with our LANDSAT-aided snow survey information. CCSS program budget information, although useful for examining the snow surveys production process as a whole, does not tell us much about the costs of producing intermediate outputs like snow density and water content measurements. Moreover, we were specifically interested in the costs of producing these outputs in our study area, the Feather River Basin, rather than for the entire state.

Intermediate output and geographical limitations led us to focus our cost analysis on individual snow course and aerial marker survey visits. Our cost model thus assumed the following appearance:

$$C_b = m c_{am} + n c_{sc} + c_i$$

Where C_b = total costs for the production of snow depth and water content data within basin b in year t

m = number of aerial marker measurement visits in year t

n = number of snow course measurement visits in year t

c_{am} = direct cost of an average aerial marker survey measurement visit

c_{sc} = direct cost of an average snow course survey measurement visit

c_i = indirect costs associated with $(m c_{am} + n c_{sc})$

Estimates for the direct costs of survey work were derived from discussions with DWR snow survey personnel. Based on 1974 survey information, we arrived at the following average cost figures:

$$c_{am} \approx \$ 15$$

$$c_{sc} \approx \$150$$

Costs of the two survey types thus differ by about a factor of ten. Aerial marker visits are relatively inexpensive because a skilled pilot can overfly and photograph many markers in a short period of time. Snow course measurement visits, because they involve detailed ground measurements, have a higher and wider range of costs. The costs of visits appear most affected by where they are and who performs them. DWR analysts estimate the direct costs of visiting the most accessible snow courses at \$50 and \$60 each. Some courses can be reached by road or easily by snowmobile or helicopter. Remote courses accessible only by foot can represent as much as \$210 each. This would include two men at \$40 per day plus expenses plus maintenance of supply cabins. Certain

cooperators, by utilizing slack personnel or by combining snow survey work with other operations, can reduce their survey costs considerably. For example, a helicopter normally renting for \$150 an hour may average only \$50 an hour when used on a regular basis.

Estimates of indirect costs are much harder to derive than direct costs. Our estimation problem is compounded because at this state of our modeling we are concerned with intermediate outputs such as water content determination. The challenge is to isolate only those indirect costs associated with the production of snow water content measurements. Indirect costs can be distinguished in the following DWR snow survey activities:

- program direction and coordination of survey work
- communication with cooperators
- preseason aerial marker and snow course setups
- measuring equipment acquisition and maintenance
- training and safety instruction sessions
- formal recording and publication of measurements

Since we have not as yet developed itemized cost estimates for the above categories, we decided to refer generally to indirect costs based on the DWR snow survey budget information discussed earlier. Salaries, plus their 67 percent overhead factor, accounted for almost 80 percent of the budget. Department time was divided almost equally between (1) snow survey activities and (2) water supply forecasting. Nearly all of the foregoing indirect cost categories fall within the survey side of the departmental budget and require extensive labor inputs from salaried personnel. We concluded that the indirect cost factor for water content estimation should thus be no more nor much less than half the overhead factor used with direct salary costs. We chose the more conservative estimate:

$$c_i = .33 (m c_{am} + n c_{sc})$$

Using the information regarding visits presented in Table 6.3, we then derived the following survey cost total for the Feather River Basin in 1974:

$$\begin{aligned} C_{FRB} &= m c_{am} + n c_{sc} + c_i \\ C_{FRB} &= 3 (\$15) + 125 (\$150) + c_i \\ &= 1.33 (3 (\$15) + 125 (\$150)) \\ &= 1.33 ((\$45) + (\$18,750)) \\ &\approx \$25,000 \end{aligned}$$

6.350 Accuracy of Surveys

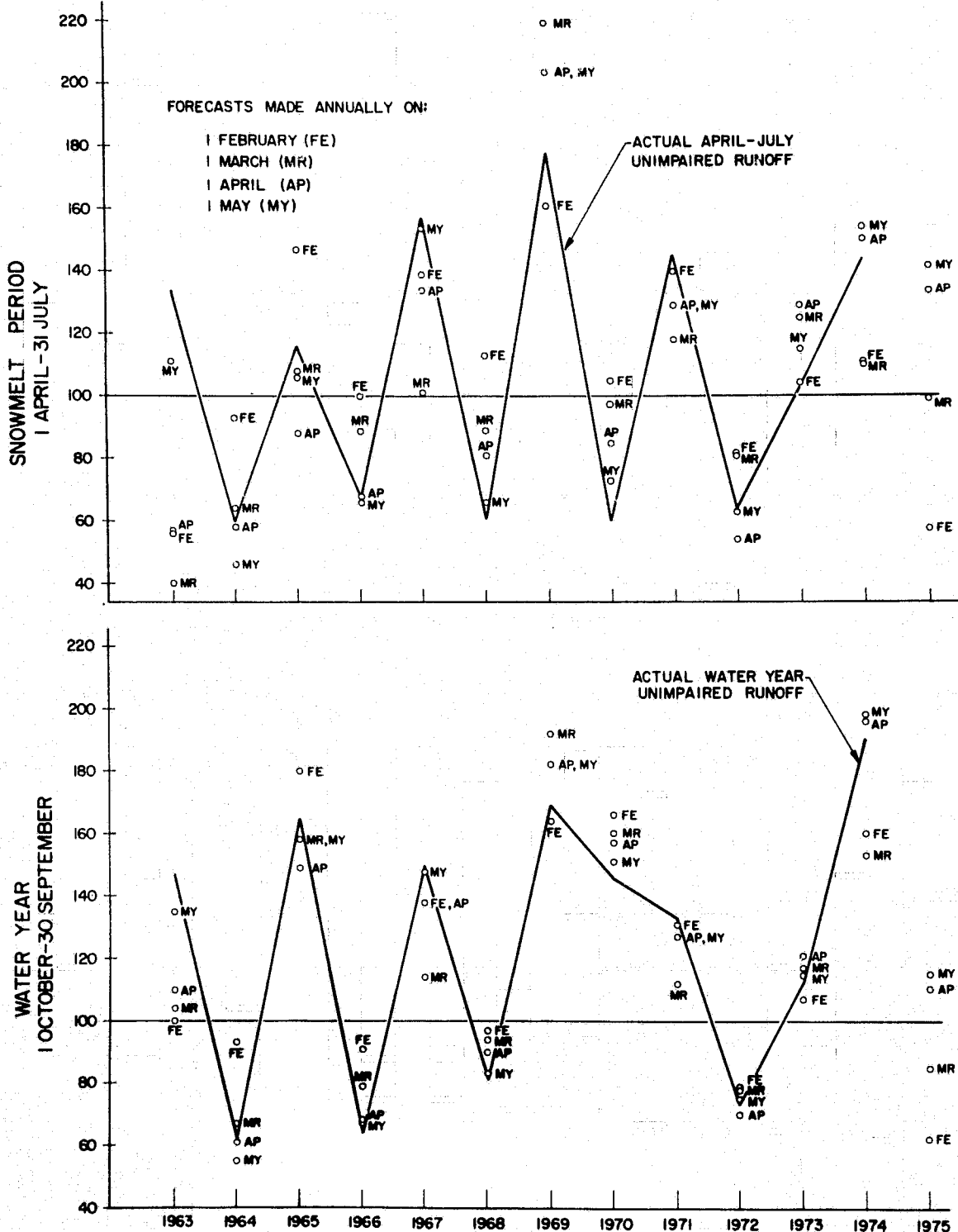
The cost model in Figure 6.2 is counterbalanced by an "effectiveness model" that relates system outputs with user needs and overall goals. Effectiveness, in the context of the snow survey program, implies determining the accuracy and associated accuracy variance of runoff forecasts. In terms of an intermediate output like snow water content, effectiveness indices can be developed by measuring the dispersion of monthly water content estimates about their mean. We performed both types of effectiveness analyses in the course of our research.

The accuracy of runoff forecasts was examined by comparing monthly forecasts of snowmelt period and water-year runoff with later records of actual runoff for years 1963 through 1974. Forecasts and recorded inflows to the Oroville Reservoir were obtained from DWR Bulletin 120 reports and data supplements. Tables 6.5A and 6.5B summarize the results of our investigation. The first table consists of two line graphs showing recorded inflows for the April-July snowmelt period (upper graph) and for this entire water year (lower graph) over a 12-year period, 1963-74. Recorded inflows are indicated as a percentage of average runoff for the period. Four points representing inflow forecasts made at the beginning of February, March, April, and May appear for each of the 12 years plus 1975. The relative accuracy of the monthly forecasts is indicated by their vertical distance from the line representing actual unimpaired runoff.

Table 6.5B presents one method of quantifying the accuracy of the monthly forecasts. Here, the vertical distances described in Table 6.5A are translated into absolute percentage errors and averaged by forecast month for the 1963-74 period. The result is a sequence of four points representing a 12-year average of the absolute errors of the February, March, April, and May forecasts for both the snowmelt (upper graph) and water year (lower graph) runoff periods. The two graphs also show standard deviation boundaries (dotted lines) around the points and coefficients of variation (in parentheses).

Inspection of Tables 6.5A and 6.5B reveals wide variability both in recorded runoff and in runoff forecasts. The zig-zag pattern of annual unimpaired runoff in Table 6.5A suggests that a "normal" water runoff season is a rare event in the Feather River Basin. Seasonal weather variability in turn affects runoff forecast accuracies. As table 6.5B shows, monthly forecasts of snowmelt period runoff since 1963 have deviated from actual runoff by an average range of from ± 36 to ± 13 percent. The corresponding range for water year forecast errors extends from ± 17 to ± 14 percent. This two to one advantage in reducing average forecast error (water year vs. snowmelt period) can be partially explained by the ability of the water year forecast to encompass more weather variability, as, for example, when the snowmelt season is extended by a late spring. Average

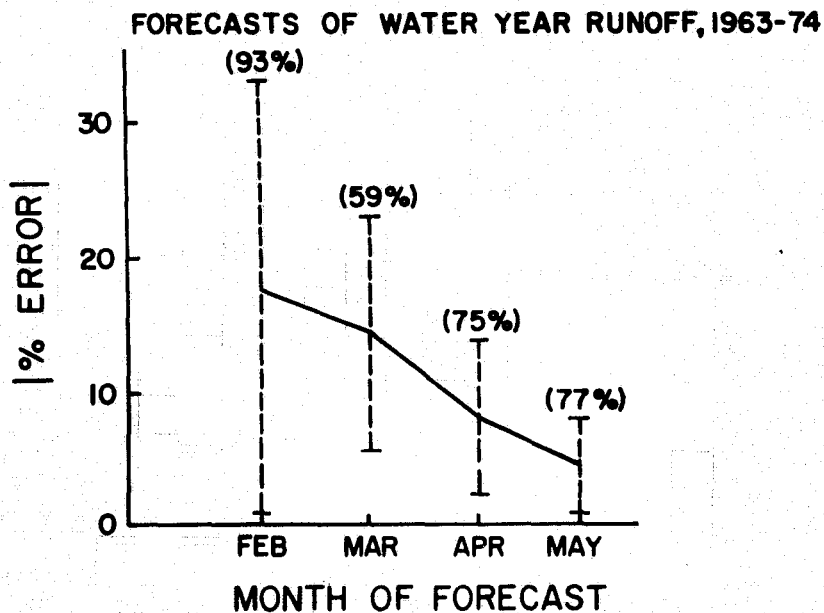
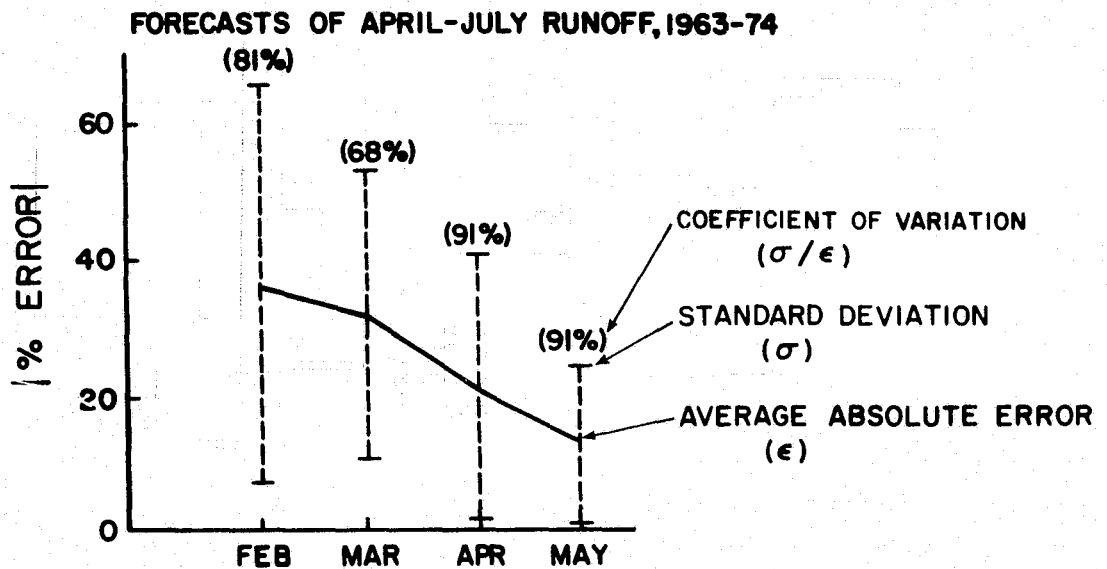
TABLE 6.5A: COMPARISON OF MONTHLY FORECASTS WITH ACTUAL RUNOFF
FEATHER RIVER BASIN: INFLOW TO OROVILLE RESERVOIR,
1963-74 *



* RUNOFF NEAR OROVILLE BEFORE 1968

SOURCE: CALIFORNIA DWR BULLETINS 120, ALL YEARS, 1963-1974

TABLE 6.5B AVERAGE ABSOLUTE ERROR IN RUNOFF FORECASTS IN OROVILLE RESERVOIR



SOURCE: CALIFORNIA DWR BULLETINS 120, ALL MONTHS, 1963-74

accuracies for both forecasts improve (absolute errors and standard deviations drop) in successive forecast months. This corresponds with the expectation that late-season forecasts should better predict total snowmelt runoff than forecasts made in early February.

Runoff forecast accuracy can be useful as an effectiveness indicator of the existing snow survey and forecasting production system. But runoff forecasts do not provide direct performance quantification for the intermediate output (snow water content) that we wish to compare our LANDSAT-derived snow survey information.

Our comparative analysis (see next section) required a common measure of relative performance. The measure selected was allowable error (AE). This quantity enables a researcher to make a probabilistic statement about an estimated value. Here, allowable error defines a confidence interval about the estimated mean water content. The true water content can be expected to fall within this interval with a given probability. Allowable error is expressed as a plus or minus percentage of the estimate mean, that is, as the half-interval width. Calculation of AE is based on a determination of the sample size (n), the coefficient of variation (CV), and a selected Student's-t value corresponding to the probability of having the true water content value fall in the calculated confidence interval. The CV, a measure of sample data dispersion about its mean, is defined as the sample's standard deviation expressed as a percentage of the sample mean.

Bulletin 120 again supplied the data for this performance determination: Feather River Basin water content measurements were summed by month (January through May) for each of four years (1971-74) to determine means, standard deviations, and thus CV's. Months with less than three samples were excluded. The results were summed by month over the four year period to determine average monthly CV's. Selections of confidence probabilities at the 1 and 2 standard error level were then made for representative performance display. Table 6.6 summarizes the results.

Examination of the AE values within Table 6.6 indicates that snow water content is estimated most precisely at the beginning of March. Higher allowable errors (i.e., lower precision for a given level of confidence) in January and February may be due to greater areal snow pack accumulation variability than in March and also perhaps due to lower pack water content stability. The lower sample rate in January also contributes to the relatively high allowable error. The May snow pack variability appears from examination of snow course data to be due to differential melt rates over the watershed. It is possible that the higher April AE may be ascribed to a large snow water content differential between high and low elevation snow courses.

In order to use allowable error as a valid measure of performance it was assumed that snow courses had been randomly allocated over the watershed. In reality this was not the case. Actually, the CCSS program employs a subjective quasi-random allocation process. The implications of this situation and justification for the use of the allowable error performance comparison criterion are discussed in Section 6.4.

6.400 COMPARATIVE ANALYSIS

In addition to ample qualitative information, judgements about the cost-effectiveness of comparable systems usually require a resourceful use of quantitative methods. Comparative analyses, in other words, must be "custom-tailored" to the uniqueness of each case example. This section describes how we applied a cost-effectiveness analytic framework to the context of our snow survey example.

6.410 Difficulties of Comparison

Real-world complications inevitably force applied cost-effectiveness analyses to deviate from their theoretical counterparts. On the cost side, the question is not one of perfection but of sufficiency. On the performance side, a balance must be struck between what we would like to

TABLE 6.6 - VARIATION AND PERFORMANCE STATISTICS FOR SNOW WATER CONTENT MEASUREMENTS, BY MONTH, FEATHER RIVER BASIN, 1971-74.

Month	No. of Snow Courses Providing Data (n)	Average Coefficient of Variation ¹ (ave. CV) (In Percent of Estimated Mean Value)	Allowable Error ² (AE) (In Percent of Estimated Mean Value)	
			68.3% Level of confidence ³ (.683 probability)	95.0% Level of confidence (.950 probability)
JAN	13	61.58	17.08	37.22
FEB	23	63.38	13.22	27.42
MAR	21	59.51	12.99	27.10
APR	29	73.17	13.59	27.83
MAY	22	94.95	20.24	42.10

1.
$$CV = \frac{\sqrt{\hat{\text{Var}}(y)}}{\hat{\bar{Y}}} \times 100$$

y = reported ave. snow water content value for a given snow course for a given month.

$\hat{\bar{Y}}$ = ave. of snow course water content values for a given month.

$\hat{\text{Var}}(y)$ = estimated variance of y.

2.
$$AE = t \cdot \frac{CV}{\sqrt{n}}$$
, where t is Student's-t and n is the number of snow courses contributing to $\hat{\bar{Y}}$.

= plus or minus percentage of the estimated mean in which the actual value of snow water content is expected to fall with probability specified via Student's-t.

3.
$$\frac{CV}{\sqrt{n}} \text{ or } \frac{\sqrt{\hat{\text{Var}}(y)}}{\sqrt{n}} \times \frac{1}{\hat{\bar{Y}}} \times 100$$
 is also known as the sampling error at the one standard error level of confidence.

measure and what can be measured with reasonable accuracy. Overriding both sides are questions concerning the comparability of different production systems.

Ideally, our own study would attempt to compare the existing DWR CCSS volumetric model with an identical model augmented with remotely-sensed snow survey information. Outputs of both models would be keyed to estimates of total water yield. Costs and accuracies would be estimated at least for the entire Feather River Basin, if not for the whole Sierra Nevada.

In reality, our study isolates those portions of the CCSS volumetric model that can be compared with LANDSAT-derived snow areal extent information developed in the University of California Remote Sensing Research Program (RSRP). An intermediate output--snow water content--is used rather than water yield. This is nevertheless a critical step toward defining the applicability of remote sensing techniques to the possible improvement of water yield forecasts. By individually examining predictor variables such as snow water content, we may determine how precision increases that are made in predictor variable estimates can lead to precision increases in overall predictions. The analysis here thus compares the relative abilities of two systems to generate an intermediate output. Costs and accuracies for the existing model are based on published reports and interviews with DWR staff. Costs and accuracies for the LANDSAT-aided model are derived from concurrent RSRP work in the Spanish Creek Watershed, an area within the Feather River Basin.

6.420 Sources of Error

Any measurement process contains inherent sources of error. One of the tasks of our research is to distinguish the various error sources embodied in the snow survey program and snow water content estimation procedure and to determine their magnitude. The following sources of error are the most obvious:

- °Weather Variability. The inability to predict future variations from normal weather patterns is probably the largest source of error within the CCSS volumetric model. As table 6.5A demonstrated, "normal" runoff seasons have been almost non-existent in recent Feather River Basin History.

- °Precipitation measurement errors. Two of the five major inputs into the CCSS model are the October to March and April to June precipitation indices. Inaccuracies introduced by these measurements directly influence runoff forecasts. One example of this error source is the relatively small number of Feather River Basin precipitation samples currently collected at higher elevations.

- Gauge station measurement errors. Runoff volume is measured by gauging station operators and later corrected for upstream impairments to arrive at unimpaired flow estimates. Errors entering this process at the time of measurement may be exaggerated during translation to an unimpaired basis. An October to March runoff index is one of the principal inputs in the CCSS volumetric model.
- Snow water content measurement error. The final two major inputs into the CCSS model are two snow pack indices, both relying extensively on snow water content measurements. Snow water content measurement errors can be introduced during snow course measurement visits or by the selection of unrepresentative snow course sites.
- Model Accuracy. Both the cost and effectiveness models used to describe snow survey outputs and intermediate outputs are vulnerable to the above-mentioned error sources and other inputs as well as to the possibility of various inaccuracies inherent in the models themselves.

At this stage of research, the major error sources have been isolated but not quantified. Continuing refinements and testing will enable us to better understand the relative magnitude of the error sources in the models under study. Eventually, we expect to be able to assess relative sensitivity of the models to all major sources of error.

6.430 Comparative Sampling Design

6.431 The LANDSAT-aided Snow Water Content Estimation System

6.431.1 Objectives

The snow water content estimation method utilized in this study with LANDSAT information is known as a stratified double sample. Its objective is to combine snow water content information for the whole watershed, as obtained inexpensively from LANDSAT data, with that gained from a much smaller and more expensive sample of ground based snow courses. In this way a large amount of the variability in basin snow water content is accounted for by use of the LANDSAT data.

The desired result is that after calibration by regression of LANDSAT data on snow course data, an overall estimate of basin snow water content is possible at significantly more precise levels than available for the same cost from snow course data alone. In addition, the associated gridding of LANDSAT data into an image sample unit system allows an in-place mapping of snow water content with respect to known melting environments and stream channels. Such in-place mapping is potentially very useful as an additional data type for improvement of hydrologic model accuracy.

6.431.2 General Procedure

The stratified double sampling plan is described mathematically in Appendix I. The method summarized in section 6.421.3, generally proceeds as follows: First, black-and-white LANDSAT transparencies are obtained and transformed to a simulated infrared color composite form (Katibah, 1973). In the color combining process an image sample unit grid is randomly placed over the image so as to cover the watershed of interest. Each image sample unit is then interpreted manually as to its average snow areal extent cover class according to a snow environment-specific technique described by Draeger and Lauer (1973) and in more detail by Katibah (see section 2.200b of this report).

Snow water content is then estimated from the following first case, time specific model:

$$X_i = \left(\sum_{j=1}^J (M_{ij})(G_j) \right) \cdot K_i \quad \text{eq. 4.1}$$

where X_i = estimated snow water content for image sample unit i ,

M_{ij} = snow cover midclass point expressed on a scale of 0.00 to 1.00 for image sample unit i on the j th LANDSAT snow season date,

G_j = weight assigned (0.00-1.00) to a past M_{ij} according to the date of the current estimate,

K_i = the number of times out of j that sample unit i has greater than zero percent snow cover, and

J = total number of snow season dates considered.

Image sample units utilized in this study represented 980 acre ground areas. Snow cover classes were defined as 0 percent, > 0 - 20 percent, > 20 - 50 percent, > 50 - 98 percent, and > 98 - 100 percent of ground covered by snow.

In order to insure reasonably high correlation between X_i and corresponding ground water content values, y_i , j should equal at least three. As a matter of operating procedure, one or two dates of LANDSAT imagery would be required during the early snow accumulation season after which LANDSAT snow water content estimation could proceed for a given date based on a semi-sliding two, three, or more date basis.

1. Investigation of more sophisticated stochastic model and physical model transforms currently under way.

Under certain circumstances j may only be two. For instance, an early snow season date and the mid-season date of interest may give rise to acceptable LANDSAT-ground correlations. Or, more powerfully, the first date may consist of an average April 1st snow water content map based on past year's LANDSAT data. In all cases the sample unit grids on all dates must be in common register with respect to a base date grid location.

In this study, three dates of LANDSAT imagery, April 4, May 10, and May 28, 1973, for the Feather River Watershed were interpreted for snow areal extent. The resulting areal extent estimates for each image sample unit were transformed to snow water content using equation 4.1. Comparison with the average snow water content for April 1 and May 1, 1973, recorded at snow courses falling in corresponding image sample units yielded a correlation coefficient of 0.85. To quantify the relationship on a time comparable basis, LANDSAT snow water content data from only the April 4 and May 10 dates were analyzed. A correlation coefficient of 0.77 was achieved² between water content data thus derived on these two LANDSAT dates and the snow course water content data in April and May. In an operational situation, however, LANDSAT data from early snow season dates would be available for improved snow water content estimation. To conservatively simulate the effect of a third date, only snow presence/absence data from May 28 were added to snow class and presence/absence data from the previous two dates. The resulting correlation coefficient, 0.80, was then used in the analysis.

After the snow water content index for each LANDSAT image sample unit has been determined, all such units are sorted into strata according to the size of their respective snow water content index. Stratification is used to control the coefficient of variation of the overall basin water content estimate. This is accomplished by the subsequent segregation of the population of image sample units into homogeneous environmental types tending to receive, accumulate, and lose snow at similar rates. Six such strata were used in the effort reported here.

Ground (snow course) sample sizes may be determined (see Appendix I) for individual strata according to the snow survey direct cost budget for the watershed of interest and according to the following stratum specific statistics: relative stratum size, LANDSAT snow water content variability, LANDSAT to ground correlation, and LANDSAT to ground sample unit cost ratio. These sample size calculations may be conducted according

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2. Ground-image sample unit spatial matching was based on the best published data (Bulletin 129). CCSS has recently plotted their Feather River Watershed snow courses on 15 minute USGS quadrangles and these data will be used to check the previous ground LANDSAT sample unit registration.

to either of two options. Both alternatives involve the measure of stratum size. The first size value consists of the sum of the snow water content indices for all image sample units in a given stratum. The second represents the total number of sample units in the given stratum. If it is desirable to direct the ground sampling to areas of higher snow water content in view of the importance of that water volume to runoff, then the first option is preferable.

In effect, the first stratum size weighting option (based on accumulated LANDSAT snow water content) allows a more finely calibrated LANDSAT estimate in areas of higher water content and potentially higher importance in runoff modeling. The effect will be a slightly less precise and less accurate estimate in the more variable low snow water content areas. The second option effectively directs the ground sample to those image strata that are most variable in terms of the snow water content index. Analysis of the Feather River data in this study indicates that such strata are generally those of extremely low snow water content.

Results of this study also show that the first stratum size weighting option (W01) gives overall basin snow water content estimates which are generally 1.4 to 1.6 times as precise as the second (W02). The hydrologist's choice among the two alternatives must ultimately be governed by the relative runoff importance ascribed to the low versus high snow water content areas.

Once stratum ground (snow course) sample sizes have been calculated for a fixed budget, the expected performance may be determined for the snow water content inventory. One standard statistical expression of performance is allowable error (AE). This value was defined previously as the half width of an interval centered on the basin estimate in which the true basin water content value is expected to fall with given confidence probability. Calculation of the expected overall coefficient of variation (CV), selection of the confidence probability (represented by Student's-t), and use of the total snow course sample size (n) allows calculation of AE according to the following formula:

$$AE = (t_{n_{total}} - 1) \cdot (CV_{overall}) \quad \text{eq. 4.2}$$

If the allowable error is not low enough to satisfy snow water content estimation objectives, a larger snow survey budget is required. In this case the hypothesized larger budget level is selected and the sample size and allowable error calculation process is repeated. It should be noted that the calculation of the overall coefficient of variation would be based in part on LANDSAT data and in part on snow course data. If snow course data are not available then first year snow water content variability estimates may be based on previous LANDSAT data or supporting time coincident aircraft data alone.

After the allowable error criterion has been met, the calculated number of necessary snow courses per stratum are allocated with equal probability to image sample units within a stratum. This allocation for a given watershed may occur once during the system setup. In such a situation, sample size and AE testing should be performed for the most variable snow water content index month of the snow season. Once the snow courses were established, cost-effective basin snow water content estimation would proceed by use of the double sample regression formulae relating LANDSAT and ground data. The resulting water content estimate would then be related in combination with other independent variables to water runoff.

Another potentially cost-information advantageous course allocation alternative is possible with the proposed stratified double sampling estimation method. This alternative would involve selecting prior to each snow season a set of ground sample units (snow courses) to be visited only that season. Selection would be based on image sample unit assignment according to previous years of LANDSAT snow water content index data. In this way much information could be gained on snow pack conditions as they related to a variety of environmental circumstances and runoff. Each month's estimate of basin snow pack water content would be an unbiased value with specified AE constraints. Utilizing an established snow or water content -- runoff relationship, runoff predictions based on the basin snow water content estimate and other common predictor variables could be made in the absence of permanent snow courses. However, in a test period, these temporary ground sample units might have to be supplemental to a set of snow courses active for several seasons that would provide established snow pack - runoff relationships.

For basins where established snow courses already exist, the snow courses would be classified into the appropriate strata. Under this third allocation method, additional courses could then be added, subtracted, or replaced where necessary according to an annual partial course replacement strategy.

6.431.3 Summary of Steps to be Used in Stratified Double Sampling for Snow Water Content Estimation

- (1) Create LANDSAT color composites with appropriate image sample unit grid over watershed(s) of interest.
- (2) Estimate snow areal extent by LANDSAT image sample unit for previous year(s) or current season snow build-up date(s).
- (3) Estimate snow areal extent by image sample unit for LANDSAT snow season date of interest.
- (4) Transform snow areal extent data to snow water content data by LANDSAT image sample unit.

- (5) If not already performed, stratify image sample units into LANDSAT snow water content index classes. Then calculate stratum ground sample unit (snow course) sample sizes to achieve allowable error criteria for the basin snow water content estimate. Stratification and sample size calculation should be performed for the pre-snow season date combination having the most variable snow water content and/or containing the largest water runoff-related snow pack.
- (6) If not already performed for the given snow season or snow season date, allocate ground sample units to strata with equal probability within strata.
- (7) Calculate the estimate of watershed snow water content according to a summation of stratum regression relationships for LANDSAT versus ground observations.
- (8) Enter the basin snow water content estimate into statistical or physical models to predict water yield.

6.431.4 Assumptions

Based on the foregoing system overview, the following assumptions may be identified for this proposed LANDSAT-aided snow water content estimation procedure.

- (1) The probability distribution (pdf = probability density function in a continuous variable formulation) of X_i , the estimated LANDSAT snow water content index for image sample unit i , is determined by examination of the 980 acre image sample units. It is assumed that this pdf is the same as the X_i pdf based on examination of 30 acre cells. These smaller cells represent the approximate ground area associated with a snow course located at the center of those 980 acre sample units.
- (2) The value of X_i for the 980 acre image sample unit will, on the statistical average, represent the X_i value for the 30 acre cell at the 980 acre sample unit center.
- (3) The image sample units can be stratified based on the value of the X_i .
- (4) Only the tendency, expressed by the correlation coefficient, of LANDSAT snow water content estimates to vary with corresponding ground measurements need exist in order to increase basin snow water content estimate precision and consequently decrease ground sample unit size. In other words, only the proportionality between X_i and y_i , and not an absolute LANDSAT snow water content estimate, is needed for the proper operation of the double sample method.
- (5) Frequency and availability of utilizable watershed LANDSAT imagery is comparable to the frequency of current ground snow course surveys.

- (6) Ground sample size over time in a given stratum must be large enough to give a reliable stratum LANDSAT-to-ground regression coefficient.

The first and second assumptions appear to be reasonably valid based on the strength of correlation coefficients calculated to date. In addition, the importance of the first two assumptions will be diminished as more area and environment specific techniques now under development (e.g., Katibah and Thomas) are applied. The third and fourth assumptions are, under definitions of the image and ground sample unit populations, statistical truisms.

The fifth assumption is generally valid in terms of frequency for several snow zone areas throughout North America. LANDSAT passes are at 18-day intervals and with a significant amount of next-day sidelap. Consequently, even when cloud patterns obscure portions of the watershed on one day, they may not do so on the following day, and vice versa. Furthermore, the development of historical correlations between nonobscured and obscured sample units may allow relatively accurate snow water content estimations to be made in the case of partial watershed cloud cover situations.

Despite the foregoing possibilities, some regions of North America may have cloud cover frequencies too high to allow effective use of LANDSAT imagery. In addition, daily water yield forecasts may be required by the public as in the case of flood forecasting. In these cases, the use of meteorological satellite information when correlated on a sample unit basis with LANDSAT and ground data offers the possibility of more frequent snow water content estimates.

LANDSAT coverage for other areas is less consistent in terms of availability than for North America. Future operational earth resource satellite and ground tracking systems may provide a better data base in this case. The use of LANDSAT-correlated meteorological satellite information would also be especially important in such areas.

Currently the availability of LANDSAT data for near real time forecasting is possible only through the making of special arrangements. Without such arrangements, the data turn-around time for snow water content information may not be rapid enough to be satisfactory.

Assumption number six, involving degrees of freedom for the LANDSAT-to-ground regression coefficient, is of concern only in those strata having a low calculated ground sample size. In this case, the regression coefficient must be refined from data collected over a number of coincident LANDSAT and ground measurement periods during the snow season. One alternative to avoid initial low degree of freedom situations, would be to oversample during the first year those strata for which low ground sample sizes have been allocated.

6.432 The Current CCSS Program Snow Water Content Estimation System

6.432.1 Objectives

As stated earlier, the objective of the California Cooperative Snow Survey Program is not to estimate snow water content per se. Rather, it is to produce information useful in the prediction of water yield. However, the precision of the snow water content estimate will affect the precision of the water runoff prediction. Thus it is appropriate to attempt to compare the relative abilities of the LANDSAT-aided and current survey systems to estimate this important water yield predictor variable.

6.432.2 General Procedure

The major features of the CCSS Program's production process and field sampling have been outlined in section 6.300 and particularly subsection 6.330. It was learned that snow courses are not currently allocated over a watershed (e.g., Feather River area) in a random fashion. Instead, the present CCSS Program snow course locations have evolved paralleling the development of snow hydrology sampling theory over the last fifty years (Howard 1974). For example, 30 to 40 years ago snow courses were located primarily according to site accessibility. The next twenty years saw criteria for new snow course location evolve to allow better areal and elevational snow zone sampling. Recently, locational criteria have emphasized snow zone positions with high runoff correlations. Some positions may not have been sampled previously.

Within a given area designated as a desirable snow course location, only certain positions presently satisfy course location criteria. These positions must be essentially open and free from extreme drift, melt, wind, and ponding (Bulletin 129, 1970).

The snow course itself consists of ten points spaced at 50 or 100 foot intervals in one or more transects. Snow depth and weight readings are taken at each point with a Mt. Rose snow sample device. The average snow water content from ten points is then defined as the course snow water content value for the given sample date. Key snow courses are visited near the beginning of each month from January through May, while all snow courses are sampled on or about April 1.

Snow depth markers associated with snow courses and a growing network of experimental automatic snow sensors, both discussed in subsection 6.330, provide supplemental information to the snow course networks.

6.432.3 Assumptions

The basic assumption of the CCSS Program's snow course allocation scheme is that the quantitative-subjective allocation plan will provide data that can be correlated with water yield. As Bulletin 129 points

out, snow course measurements should not be taken as an accurate measure of snow water content over a large area without careful study of both the snow course and the area of interest.

It is clear that the proposed LANDSAT-aided and the current CCSS Program snow water content estimation systems are not identical. However, if the two systems' products are utilized similarly and are based on a concept concerning a representative quantification of the characteristics of watershed snow pack, then a common measure of relative system performance is possible. The intermediate products of both systems are designed to be utilized in water yield prediction. The error of either will affect the runoff prediction in a similar manner. Both are intended to characterize, at least in part, the general variability of the snow pack as it relates to water content.

A common statistical measure of performance is therefore implied. The often-used criterion of probability sampling, known as allowable error (AE) is appropriate here. Consequently, the CCSS snow course system must be considered as a random sample for comparison. To make this assumption and insure an equitable comparison requires that an especially favorable assumption toward the CCSS system be made. This additional assumption is that the CCSS snow courses are randomly located over the entire watershed. In fact, however, they are allocated only to the zone receiving snow that is resident on the ground for significant periods during the middle of the snow season. The result is that CCSS snow water content data will have a smaller coefficient of variation than would be expected if ground sample units were in fact allocated over the entire watershed.

Two sampling frameworks have been considered for the CCSS data in order to allow the best comparability possible between the LANDSAT-based and current snow water content estimation systems. The first considers the CCSS snow course data as a purely random sample with all observations having equal weights. The results are then directly comparable to those obtained with the LANDSAT stratum size weighting option based on the number of image sample units in a given snow water content stratum.

The second sampling framework also considers the CCSS snow courses as randomly allocated to image sample units over the watershed. However, snow course data are not weighted equally in estimation of total basin snow water content. Rather they are assigned weights proportional to the water content index size of the LANDSAT stratum into which the corresponding image sample unit falls. This procedure enables a direct comparison of CCSS results and the first stratum size weighting option discussed in subsection 4.212.

6.440 Performance Comparison

The overall performance of the two snow survey systems was compared in a manner analogous to the cost-effectiveness diagram portrayed in Figure 6.1. This performance comparison was facilitated by identification

of three comparative elements: unit costs, sample sizes, and precision. Each is described in turn in the following paragraphs.

6.441 Unit Costs

Since the collection of samples at snow courses is an activity common to the LANDSAT-aided and the existing snow survey methods, it was possible to apply the same set of costs per ground sample unit to both systems. The unit costs of typical snow course measurement visits were estimated earlier at \$150 each (See Section 6.340).

Costs per image sample unit, applicable to only the LANDSAT-aided survey system, are presented in Table 6.7. These costs were developed along with the sampling methodology described in Section 6.431, and are derived from actual University RSRP snow survey work using 2218 image sample units in the Feather River Watershed. Pre-inventory and inventory costs are shown on both a total cost and cost per image sample unit basis.

The average cost for each of the 2218 image sample units was 13.6¢, of which about 10¢ went toward image interpretation and keypunching. Since most of the processed and unprocessed imagery is useful for later training and comparative analysis, an amortization factor was applied. It was assumed, for example, that two out of three dates of imagery developed for one occasion would be usable over a total of five separate occasions. Specific assumptions about amortization schedules are described in Table 6.7.

6.442 Sample Size

Previous sections have already discussed the sample size determination method employed by the existing snow survey system. The "subjective quasi-random allocation process" described in subsection 6.350 is tailored to fit general CCSS program budget constraints. In subsection 6.340, the 1974 budget for the Feather River Basin snow survey work was estimated at \$25,000. This was sufficient for 125 snow course measurement visits and 3 aerial marker measurement visits.

The methodology behind sample size determination in the LANDSAT-based system was mentioned in subsection 6.431.2 and developed more fully in Appendix I. Table 6.8 shows the number of samples required under various assumptions about budget levels, sample costs, and weighting options. In the LANDSAT-based system, a relatively small number of snow course measurement visits, or ground sample units (GSU's), are supplemented by 2,218 image sample units (ISU's) covering all but about 5 percent of the Feather River Basin. As described previously, both GSU's and ISU's are allocated among six environmental strata.

For research efficiency purposes, image sample statistics used in calculating sample sizes are based on Spanish Creek Watershed data.

TABLE 6.7 - IMAGE SAMPLE UNIT COSTS FOR A LANDSAT-BASED MANUAL SNOW WATER
CONTENT INVENTORY

	<u>Total Cost</u>	<u>Cost per ISU¹</u>
I. Pre-Inventory		
A. Image Acquisition		
3 LANDSAT dates with 3 bands per date @ \$3 per band; the costs of 2 of these dates amortized over 5 dates	\$12.60	\$.006
Resource Photography (Medium Scale Aerial Photography for Image Analyst Environmental Type Training)	\$14.29	\$.006 ²
B. Image Sample Unit		
Gridded LANDSAT Color Composite Print Generation		
Film, Processing, and Printing		
3 dates @ \$11 per date		
The costs of 2 of these dates amortized over 5 dates	\$15.40	\$.007
Labor 0.5 hours per date @\$13.50/hr including overhead, 3 dates, the costs of 2 of which are amortized over 5 dates	\$ 9.45	\$.004

-
1. Cost per image sample unit assuming 2218 image sample units in the watershed(s) of interest.
 2. Two \$500 flights amortized over 5 years, 7 dates per year, and two watersheds.

TABLE 6.7 (continued)

	<u>Total Cost</u>	<u>Cost per ISU</u>
II. Inventory		
A. Interpreter Training		
1 hr per date, @ \$13.50/hr 3 dates, the costs of 2 of which are amortized over 5 dates	\$18.90	\$.009
B. Image Interpretation		
Ave. 6 hrs per date @ \$13.50/hr (2218 Image Sample Units)		
3 dates, the costs of 2 of which are amortized over 5 dates	\$113.40	\$.051
C. Data Key punching		
6 hrs per date @ \$13.50/hr; 3 dates, the costs of 2 of which are amortized over 5 dates	\$113.40	\$.051
D. Computer Analysis of Image Analyst Results		
0.075/hr @ \$40/hr	\$ 3.00	\$.001
E. Selection of Random Numbers to Define Ground Sample Units		
0.5/hr @ \$13.50/hr amortized over 5 dates @ \$13.50/hr	<u>\$ 1.35</u>	<u>\$.001</u>
TOTAL	\$301.79	\$.136

GIVEN:

Monthly Direct Cost Budget	Cost per GSU c_n	Cost per ISU c_n	Weighting Option
C_{direct}			

---For all Alternatives---

\$1,000	\$150	\$.12	W01 W02
3,000			W01 W02
5,000			W01 W02
7,000			W01 W02
\$1,000	\$150	\$.15	W01 W02
3,000			W01 W02
5,000			W01 W02
7,000			W01 W02
\$4,200	\$150	\$.12	W01 W02
\$4,200		\$.15	W01 W02

151

GSU

CSU

CEI

The Spanish Creek unit is a sub-basin of the Feather River Watershed. The necessary assumption to validate the use of the Spanish Creek statistics is that the distribution of snow water content classes is approximately the same in both basins. This assumption is justified by inspection of the LANDSAT snow areal extent data for the Feather's 2,218 image sample units and the corresponding 141 Spanish Creek image sample units for the snow season dates investigated. LANDSAT to ground correlation coefficients used in the sample size calculations are based on Feather River basin-wide analysis. Appendix II gives numerical results for statistics used in calculation of LANDSAT-based sample sizes.

The budget levels in Table 6.8 represent the monthly direct costs allocatable to snow survey work. Budget alternatives appear at the \$1,000, \$3,000, \$4,200, \$5,000 and \$7,000 levels. These levels compare with an estimated monthly direct cost in the CCSS program of \$4,200.³

3. From subsection 3.4, the total annual estimated snow survey budget is:

$$C_{FRB} = (mc_{am} + nc_{sc}) + c_i$$

$$\text{or } \$25,000 \approx \$18,800 + \$6,200$$

Total	Direct	Indirect
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If we assume that direct and indirect snow survey costs accrue uniformly over the snow sampling season, we can estimate how much of the annual snow survey budget is consumed in a "typical" snow survey month.

April and May are "typical" months in our study. Therefore, developing weights from Table 6.6, we can derive a monthly proportionality factor, f:

$$f = \frac{\frac{n_{APR}}{\sum n + 5} + \frac{n_{MAY}}{\sum n + 5}}{2}$$

$$f = \frac{\frac{29}{113} + \frac{22}{113}}{2}$$

$$f = .23$$

By applying f to the annual budget equation, we can derive a monthly estimated snow survey budget:

$$f [C_{FRB}] = f [(mc_{am} + nc_{sc}) + c_i]$$

$$\text{or } \begin{array}{rcl} \$5,600 & \approx & \$4,200 + \$1,400 \\ \text{Total} & & \text{Direct} \quad \text{Indirect} \end{array}$$

Unit costs for the LANDSAT-based system are calculated at the \$150 level for each GSU and at 12¢ and 15¢ levels for each ISU. Actual image sample unit costs, as presented in Table 6.7 totaled to 13.6¢. Table 6.8 also shows the effect of the two weighting options described in subsection 6.421.2. With the first, W01, sampling is based on LANDSAT-developed strata boundaries. With the second, W02, sample units are selected in accordance with established techniques of stratified random double sampling.

Resulting sample sizes appear on the right side of Table 6.8. The allocation of the 2,218 ISU's remains the same under each of the alternatives. The number of GSU's increases rapidly as the monthly direct cost budget is increased, but the number and allocation of GSU's is only slightly affected by a 3¢ increase in image sample unit costs. As mentioned before, the two weighting options place different stress on areas of high water content. W01 directs ground samples to these areas, while W02 encourages greater sampling of strata with lower water content.

6.443 Precision

Use of the allowable error (AE) formulation described in subsections 6.350 and 6.421.2 permits a direct cost-capability comparison of the two snow water content estimation systems. Allowable errors were calculated using equation 4.2 for each of the LANDSAT-based sample sizes shown in Table 6.8. AE's are produced for monthly direct cost budgets of \$1,000, \$3,000, \$5,000 and \$7,000, as well as for confidence levels ranging from 80% to 99%. Table 6.9 summarizes AE results for the two weighting options at the 15¢ per ISU level. In addition to AE, confidence level, and budget, Table 6.9 presents coefficients of variation (CV's), Student's-t factors, and the ground sample size appropriate at each CV level.

Table 6.10 presents a corresponding set of AE results for the CCSS system of snow water content estimation. AE's are calculated for four confidence levels on a monthly direct cost budget of \$4,200. Appendix III gives the analysis for calculation of allowable error associated with present snow course data. The \$4,200 budget level per survey month is our best estimate of the CCSS program's direct costs in the Feather River Basin in 1974. Derivation of the estimate appears in Footnote 3.

The budget and AE relationships presented in Tables 6.9 and 6.10 are translated into graphical form in Figure 6.3. Two graphs are shown, one for each of the weighting options. Instead of a single cost-capability frontier as in Figure 6.1, Figure 6.3 shows a family of production possibility frontiers with four confidence levels ranging from 80% to 99%. At the \$3,000 monthly budget level, for example, a LANDSAT-based snow water content sampling system (in the Feather River Basin) could be expected to produce results with a +4.3% AE nine times out of ten or at a +5.2% AE ninety-five times out of a hundred.

One production possibility of the existing system of snow water content estimation is represented by a family of points at the \$4,200 monthly budget level. These points were developed in Table 6.10 for

TABLE 6.9 - SUMMARY OF LANDSAT-BASED SNOW WATER CONTENT ESTIMATION PRECISION

Weighting Option 1 (W01)

Cost per ISU = 15¢

Confidence Level (%) 1- α	Monthly Budget (\$)	CV	t	d.f. + 1	AE (%)
99	1000	4.60	5.841	4	26.87
99	3000	2.49	2.878	19	7.17
99	5000	1.92	2.743	32	5.27
99	7000	1.60	2.690	46	4.30
95	1000	4.60	3.182	4	14.64
95	3000	2.49	2.101	19	5.23
95	5000	1.92	2.040	32	3.92
95	7000	1.60	2.015	46	3.22
90	1000	4.60	2.353	4	10.82
90	3000	2.49	1.734	19	4.32
90	5000	1.92	1.695	32	3.25
90	7000	1.60	1.681	46	2.67
80	1000	4.60	1.638	4	7.53
80	3000	2.49	1.330	19	3.31
80	5000	1.92	1.309	32	2.51
80	7000	1.60	1.308	46	2.09

Weighting Option 2 (W02)

Cost per ISU = 15¢

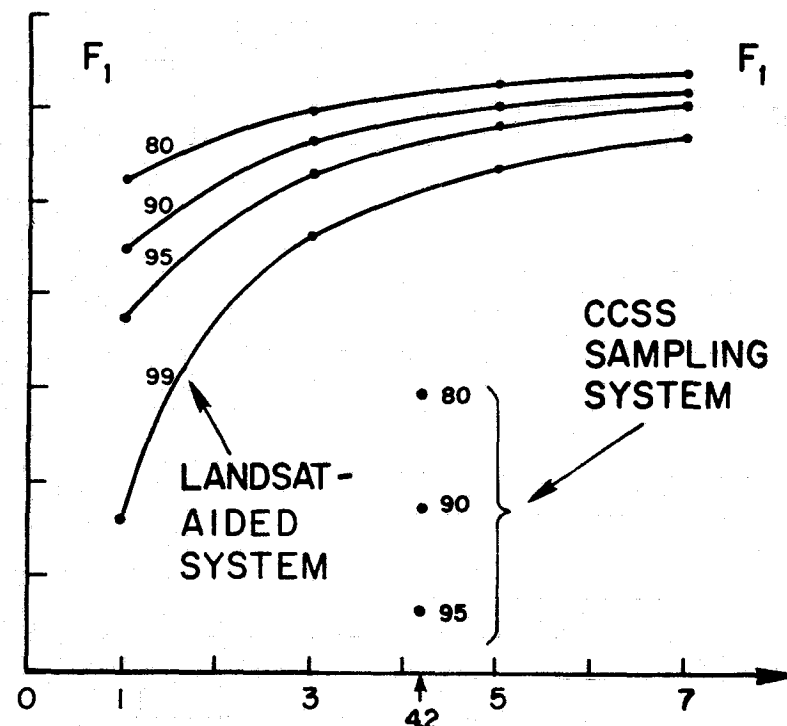
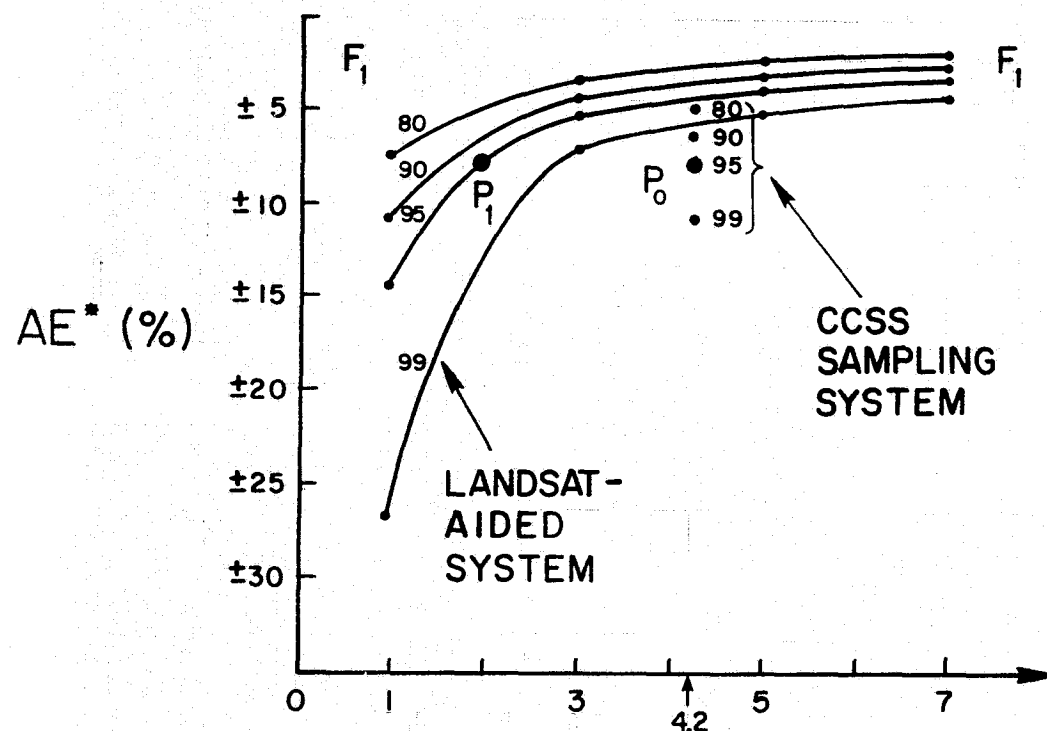
99	1000	5.98	4.604	5	27.53
99	3000	3.97	2.898	18	11.51
99	5000	2.98	2.750	31	8.20
99	7000	2.47	2.690	45	6.64
95	1000	5.98	2.776	5	16.60
95	3000	3.97	2.110	18	8.38
95	5000	2.98	2.042	31	6.09
95	7000	2.47	2.016	45	4.98
90	1000	5.98	2.132	5	12.75
90	3000	3.97	1.740	18	6.91
90	5000	2.98	1.697	31	5.06
90	7000	2.47	1.680	45	4.15
80	1000	5.98	1.533	5	9.17
80	3000	3.97	1.333	18	5.29
80	5000	2.98	1.310	31	3.90
80	7000	2.47	1.301	45	3.21

FIGURE 6.3: COST-CAPABILITY COMPARISON OF SNOW WATER CONTENT SAMPLING SYSTEMS

FEATHER RIVER BASIN 1973

WEIGHTING OPTION 1

WEIGHTING OPTION 2



* ALLOWABLE ERROR AT 80%, 90%, 95%, AND 99% LEVELS OF CONFIDENCE

TABLE 6.10 - SUMMARY OF CCSS SNOW WATER CONTENT ESTIMATION PRECISION

Weighting Option 1 (W01)

Cost per ISU = 15¢

Confidence Level (%) $1-\alpha$	Monthly Budget (\$)	CV overall	t @ d.f.=20	AE (%)
99	4200	17.47	2.845	10.85
95	4200	17.47	2.086	7.95
90	4200	17.47	1.725	6.58
80	4200	17.47	1.325	5.05

Weighting Option 2 (W02)

Cost per ISU = 15¢

99	4200	70.29	2.845	43.64
95	4200	70.29	2.086	32.00
90	4200	70.29	1.725	26.46
80	4200	70.29	1.325	20.32

the 80%, 90%, 95%, and 99% confidence levels, and are directly comparable with the family of curves developed for the LANDSAT-based sampling system. Point P_0 identifies the CCSS system's production possibility at the 95% level of confidence. Point P_1 identifies an output of similar precision and accuracy in the LANDSAT-based system. The cost advantage per snow survey month is represented by the distance between P_0 and P_1 . In this case, under weighting option 1, the LANDSAT-based sampling system shows approximately a \$2,300 savings over the existing system. The two systems may be similarly compared at other confidence levels.

In addition to facilitating direct cost comparisons between systems, Figure 6.3 also portrays how sampling precision is affected by the two weighting options. Both systems show greater precision with W01 than with W02. The existing snow water content estimation system, however, demonstrates a four-fold improvement with W01 over W02. Such evidence indicates that existing sampling techniques could be significantly improved by using strata boundaries similar to those in the LANDSAT-based system.

6.500 CONCLUSION

6.510 Summary

This chapter has described a study comparing two technologies for gathering water supply information. The study has been guided by an objective outlined in our May 1974 progress report: i.e., to see if remote sensing data from LANDSAT can be cost-effectively integrated with data used in existing hydrologic models to produce improved water supply estimates.

At this stage of our research, we have focused attention on a major predictor variable and intermediate output of the existing water supply forecasting system--the snow water content estimate. Our operating objective thus has been to compare the performance of the existing system to produce snow water content estimates with that of an LANDSAT-aided system. "Performance" in this context refers to both the cost and precision of the output estimates.

For comparative analyses, cost-effectiveness theory requires that competing systems satisfy similar organizational objectives. This restriction facilitates a side-by-side examination of comparable systems by enabling a decision-maker to assess the marginal advantage promised by alternative systems either in (1) cost savings at various levels of effectiveness, or in (2) effectiveness increases at various budget levels.

The California Cooperative Snow Survey program, the existing production system of water supply forecasts in California, was examined qualitatively and quantitatively. The study looked at the CCSS production process, their budget, and their snow surveys. Preliminary results showed that the cost of this snow survey and runoff forecasting program ranges between

\$300,000 and \$500,000 per year. In comparison, the annual cost of snow survey work in the Feather River Basin was estimated at \$25,000. The average direct cost of measuring snow water content at each of the state's 323 snow courses was estimated at \$150 per measurement visit.

Automatic processing of LANDSAT-1 imagery makes possible an alternative system of producing snow water content estimates. Using a stratified double sampling scheme, LANDSAT data for three dates were selected to augment conventional snow course measurements. Individual image sample units (ISU's) were interpreted manually according to environmentally-specific snow areal extent cover classes. The watershed was stratified into six strata (by snow water content index) to control the variability of the overall basin snow water content estimate. In addition, two stratum size weighting options were developed: in the first, W01, ground sample units (GSU's) were selected according to LANDSAT-developed strata boundaries in the second, W02, ground samples were selected in accordance with conventional techniques of stratified random double sampling. A total of 2,218 ISU's at a cost of 13.6¢ each were utilized in the Feather River Basin. These were combined with a much smaller number of GSU's (snow course measurements) at \$150 each to produce a range of performance characteristics for snow water content estimates at alternative budgets and precision levels.

A comparison of the two systems' performance characteristics indicates a decided advantage for the LANDSAT-aided system of snow water content estimation. Our principal conclusions are listed below.

6.520 Major Conclusions

6.521 Cost Savings

Total estimated costs of the two production systems may be compared at many levels of effectiveness. Figure 6.3 showed the CCSS system producing at a direct cost budget level of \$4,200 per snow survey month; point P₀ identified one production possibility at that budget. Point P₁, representing an output of equivalent precision and accuracy on the LANDSAT-aided system's production schedule, showed a \$2,300 cost savings. Extrapolated over the full range of survey months, this would imply a savings of around 50 percent (\$13,300) over the existing annual snow survey budget for the Feather River Basin.

6.522 Increased Precision

Advantages of the LANDSAT-aided system are also apparent on the capability or effectiveness side. At a given budget level, the proposed snow water content estimation system produced results 4.9 times more precise than the existing system when W02 was applied. Under W01, the LANDSAT-aided system was more than 1.8 times more precise than the current CCSS system when existing snow courses were stratified into snow water content strata based on LANDSAT data. Without this stratification, the LANDSAT-aided system (under W01) was 7.2 times more precise than the conventional approach. A comparison of weighting options showed that the

LANDSAT-aided system under W01 estimated overall watershed snow water content with approximately 1.0 to 1.6 times the precision of the same system using W02.

The LANDSAT-aided system with weighting option 1 yielded the most precise estimates of total watershed snow water content. For a \$5,000 monthly budget, this approach estimated true basin snow water content to within $\pm 3.92\%$ ninety-five times out of a hundred. The precision of basin water content estimates could be improved still further by using techniques that increase the correlation of orbital to ground snow water content estimates. Smaller image sample units, more environment-specific snow class interpretations, and automatic processing of satellite digital data are some of the more promising of these techniques.

The choice between weighting options is dependent upon the researcher's objectives. W02 will give more precise estimates for fringe snow zone areas. If fringe areas are important during some periods of flood forecasting, then W02 with the LANDSAT-aided system will produce the better results. However, if overall basin snow water content is highly correlated with either short- or long-term water yield, then W01 is more appropriate.

6.523 Additional Abilities

The LANDSAT snow areal extent-snow water content transform presented here is only a first case model. Yet it yields correlations with ground sample data on the order of .80. More sophisticated stochastic and physical transform models now being developed should push this correlation significantly higher. The result will be greater snow water content estimation precision at the same level of budget.

The LANDSAT-to-ground correlation coefficient of .80 was achieved using satellite imagery specific to two ground survey dates plus minimal information from a third date. In an operational situation, however, detailed early-season and/or previous-snow-season LANDSAT data would be available in combination with the snow date of interest, this additional information should further increase the correlation coefficient and produce an even more cost-effective snow water content estimation.

A LANDSAT-aided snow water content estimation system offers several additional possibilities for future snow survey work:

- One byproduct of the LANDSAT-derived image sample unit data is an in-place mapping of snow water content with respect to known melting environments and stream channels. Such time- and place-specific snow melt records could be used to aid in the selection of new snow course sites or in the placement of automatic snow sensors. Snow pack and stream channel juxtaposition data could also be used in refined models of runoff timing.

- Human and automatic analysis of daily meteorological satellite data, when correlated with less frequent LANDSAT and ground data, offers the possibility of extremely frequent watershed snow water content updating.
- Hydrologic models of the future will conceivably integrate remote-sensing and meteorological data with automatic ground-based snow sensing equipment. Real-time information eventually could be generated for entire watersheds of subbasins, depending on the need to assess the impact of a major storm or a minor subdivision. The continued refinement of remote sensing-aided snow water runoff estimation procedures is likely to be a necessary input into future water resource management practices.

6.530 Major Recommendations

The foregoing conclusions suggest that remote sensing promises great potential for aiding in the snow water content estimation process. Our findings are further enhanced by the fact that snow water runoff is one of the major sources of water supply within the California Water Plan, as well as in many other parts of the world. Improved methods of identifying monitoring, mapping, and modeling our snow water resources at this time can lead to improved methods of predicting and managing this resource in the future. LANDSAT-derived imagery, when used to augment an existing hydrologic model, thus appears to resemble a classic "technological advance" as defined in a cost-effectiveness framework.

Our conclusions, however, should remain tentative pending additional study. We can identify a number of activities and tasks to be performed in a variety of areas, but most of them can be classified into simultaneous work on modeling, testing, evaluation, and implementation processes. These categories are discussed below in pairs.

6.531 Modeling and Testing Process

Back in the production process diagrammed in Figure 6.2, we described how various inputs were transformed into the California Cooperative Snow Survey program's snow water forecasting outputs. The proposed LANDSAT-aided system augments those inputs with remote sensing imagery and slightly modifies the subsystem components that produce the intermediate output of snow water content estimates. In this context, the following tasks can be suggested:

- More work is needed to refine the integration of LANDSAT data with the CCSS (volumetric) model. This would entail experimenting with methods to produce more precise snow water content estimates as well as examining other parameters in addition to water content estimates.
- Other hydrologic models such as the dynamic CCSS model or the River Forecasting Center model should be tested to see if LANDSAT-derived inputs can be employed successfully.

- Other data inputs such as meteorological data should be examined to see how a combination of LANDSAT and meteorological data might be used to enhance the availability and precision of existing snow water runoff forecasts.
- Additional studies should be performed in other watersheds to compare with our Feather River Basin study. Such studies could help verify our results as well as isolate particular basin-specific parameters which influence snow water content estimates.

6.532 Evaluation and Implementation Process

The Figure 6.2 production process diagram is also useful for portraying the close relationship between all four of our categories. Evaluation is a necessary part of a comparative test run between models; the implementation process helps define how the system may be better organized to meet the needs of recipients. We can suggest several remaining tasks in the evaluation and implementation areas:

- Existing cost and effectiveness results should be further verified, refined, and expanded. The CCSS cost estimates are still very rough and can use additional scrutiny. Likewise, RSRP cost estimates and precision results should be compared with similar work when completed in the future. Broadening the analysis to include capital costs is also important. Potential users must consider start-up costs before they can implement a potentially more effective information-gathering system.
- An examination of sensitivity issues should logically follow additional test cases. For example, it would be useful to know how snow water content estimations are affected by specific changes in latitude, climate, and geography.
- An extension of the analysis into benefits issues is also a necessary part of a thorough evaluation process. Cost-effectiveness analysis measures benefits in terms of cost savings. By studying the primary and secondary net benefits accruing from more frequent and more precise information, we can better identify the ultimate beneficiaries and the value of the cost savings to them.
- A strong user orientation is required in any technological application process. Identification of beneficiary groups is a help in this direction, but actual implementation of a LANDSAT-aided snow water content estimation system would involve close collaboration with user-agency personnel and significant technical assistance. With sufficient encouragement from potential user-agencies, the RSRP should be prepared to help furnish the expertise necessary for testing LANDSAT-aided models in a more operational environment.

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APPENDIX I - SAMPLE SIZE DETERMINATION FOR WATERSHED SNOW WATER CONTENT ESTIMATION UTILIZING STRATIFIED DOUBLE SAMPLING WITH REGRESSION ESTIMATION

The objective of this appendix is to present, and in some cases to derive, optimal sample size and relative sampling rate formulas that will minimize the estimated variance of the quantity (total watershed snow water content) to be estimated. Much of the mathematical discussion builds on material presented by Cochran (1963) and Raj (1968).

The sampling design proposed for precise estimation of total watershed snow water content is known as stratified double sampling. With this approach, the watershed as depicted on a satellite image is separated into a continuous grid of rectangular sampling units. For each sampling unit, i , an estimate is made of the areal extent of snow as interpreted from satellite imagery. These decisions are based on known vegetation-terrain-snow extent relationships and appearances on the imagery. These estimates for each sampling unit are then transformed into a snow water content value, X_i , based on multiple date satellite data.

The significant advantage of this approach is that snow-state information is available for the whole watershed. A very small ground sample of the sample units depicted on the imagery gives rise to actual snow water content values, y_i . These ground values may then be used to calibrate, through a regression model, the satellite data. Since satellite information significantly correlated to snow variability is available from throughout the basin, the calibrated estimate leads to

a more precise estimation of snow water content than possible through ground simple random sampling alone. Stratification of the image sample units into classes based on the relative size of the satellite snow water content estimates increases further the precision of estimation. In general double sampling will be preferred to ground simple random sampling in a given stratum if (based on Cochran 1963)

$$\rho_h^2 > \frac{4c_{n_h} c_{n'_h}}{(c_{n_h} + c_{n'_h})^2}, \quad \text{eq. 1.1}$$

where

h = stratum index,

$\hat{\rho}_h$ = estimated correlation between image and ground data values for stratum h ,

c_{n_h} = unit direct cost of obtaining data from a ground sample unit in stratum h , and

$c_{n'_h}$ = unit direct cost of obtaining data from an image sample unit in stratum h .

The estimation model for a given stratum is assumed to be a simple linear regression relationship relating image and ground data as follows.

$$\hat{Y}_h = A_h N_h \hat{\bar{Y}} = A_h N_h (\hat{\bar{y}}_h + b_h (\hat{\bar{x}}_h - \hat{\bar{x}}_h)) \quad \text{eq. 1.2}$$

where

h = stratum index,

\hat{Y}_h = total of estimated quantity (snow water content) for stratum h ,

$\hat{\bar{Y}}_h$ = estimated mean of quantity for stratum h ,

A_h = area per image sample unit,

N_h = total number of image sample units in stratum h ,

$\hat{\bar{y}}_h$ = estimated average quantity for stratum h based on
a sample of ground sample units,

$\hat{\bar{x}}_h$ = estimated average quantity for stratum h for a
sample of image sample units corresponding
spatially to the ground units sampled,

$\hat{\bar{X}}_h$ = estimated average quantity for stratum h,
based on the estimates from all image sample
units in stratum h, and

b_h = estimated regression coefficient between y_h and x_h .

An estimate for the total snow water content over all strata in the
area of interest is given by

$$\hat{\bar{Y}}_{\text{total}} = \sum_{h=1}^L \hat{\bar{y}}_h \quad \text{eq. 1.3}$$

where

L = total number of strata.

Noting the relationship in equation 1.2 between $\hat{\bar{y}}_h$ and $\hat{\bar{X}}_h$ it may
be concluded that sample size determinations to meet precision criteria
for either will be the same. Thus for convenience, the following
sampling rate derivations will be expressed for estimation of $\hat{\bar{Y}}_{\text{total}}$.

The optimum sampling rate between image and ground sample units
for a given stratum may be derived (Thomas 1974 based on Cochran 1963) as

$$\lambda_{\text{opt}_h} = \frac{n_h}{n'_h} = \sqrt{\left(\frac{(1 - \hat{\rho}_h)^2}{\hat{\rho}_h^2} \right) \cdot \frac{c_{n'_h}}{c_{n_h}}} \quad \text{eq. 1.4}$$

where

n_h = ground sample size for stratum h, and

n'_h = image sample size for stratum h.

It can be shown that for mean quantity estimation the optimal ratio of ground sample size for stratum h to the total ground sample size is (Thomas 1974)

$$\frac{n_h}{n_{\text{total}}} = \frac{N_h \hat{S}_h (1 - \hat{\rho}_h^2 (1 - \lambda_{\text{opt}_h}))^{\frac{1}{2}} / \sqrt{c_h}}{\sum_{h=1}^L (N_h \hat{S}_h (1 - \hat{\rho}_h^2 (1 - \lambda_{\text{opt}_h}))^{\frac{1}{2}} / \sqrt{c_h}} \quad \text{eq. 1.5}$$

where

N_h = total number of image sample units in stratum h ,

\hat{S}_h = estimated standard deviation for sample unit data values in stratum h based on ground sample information if available, otherwise based on image sample unit data,

$$\hat{S}_{st_h} = \hat{S}_h (1 - \hat{\rho}_h^2 (1 - \lambda_{\text{opt}_h}))^{\frac{1}{2}},$$

= estimated standard deviation of the estimate for stratum h , and

$$c_h = (\lambda_{\text{opt}_h}) c_{n_h} + (1 - \lambda_{\text{opt}_h}) c_{n'_h} \quad \text{eq. 1.6}$$

= optimal average ground plus image sample direct cost per sample unit

Dividing both sides of equation 1.5 by the inverse of \hat{Y}_h , the average estimated snow water content per image sample unit in stratum h , gives

$$\frac{n_h}{n_{\text{total}}} = \frac{N_h CV_h (1 - \hat{\rho}_h^2 (1 - \lambda_{\text{opt}_h}))^{\frac{1}{2}} / \sqrt{c_h}}{\sum_{h=1}^L (N_h CV_h (1 - \hat{\rho}_h^2 (1 - \lambda_{\text{opt}_h}))^{\frac{1}{2}} / \sqrt{c_h}} \quad \text{eq. 1.7}$$

where

CV_h = the coefficient of variation for stratum h.

This value is often multiplied by 100 so as to be expressed as a percentage value.

When N_h is used to represent stratum size as in eq. 1.7, then weighting option 2 (W02) is used in defining n_h/n_{total} . Under W02 those strata with the largest area and most variability, given constant $\hat{\rho}_h$ and c_h , will be sampled most intensively on the ground. As it often happens in major watersheds, the most variable and sometimes larger strata will be those occupying fringe snow zone areas. Hence eq. 1.6 will tend to allocate ground sample concentrations to strata containing relatively small snow water content totals. If snow quantity in these strata is highly correlated to water yield in near real-time forecasting situations, then this weighting option may be preferred. This option would then give the most precise estimates for those relatively low total snow water content strata.

However, if the snow water content for high total water content strata is most important to either real-time water yield or longer term water supply forecasting, then another weighting option (W01) is preferable. W01 is based on stratum weights defined by the accumulated snow water content estimate over all image sample units in that stratum.

That is

$$\hat{X}_h = \frac{1}{l_h} \sum_{i=1}^{l_h} X_{hi} \quad \text{eq. 1.8}$$

where

l_h = total number of image sample units in stratum h,
and

X_{hi} = snow water content estimate for image sample i
in stratum h.

Thus for W0 1 we have

$$\frac{n_h}{n_{total}} = \frac{\hat{X}_h CV_h (1-\hat{\rho}_h^2 (1-\lambda_{opt_h}))^{\frac{1}{2}} / \sqrt{c_h}}{\sum_{h=1}^L (\hat{X}_h CV_h (1-\hat{\rho}_h^2 (1-\lambda_{opt_h}))^{\frac{1}{2}} / \sqrt{c_h})} \quad \text{eq. 1.9}$$

When total budget is fixed, n_{total} may be calculated by (Thomas 1974)

$$n_{total} = \frac{(C-c_o) \sum_{h=1}^L (N_h CV_h (1-\hat{\rho}_h^2 (1-\lambda_{opt_h}))^{\frac{1}{2}} / \sqrt{c_h})}{\sum_{h=1}^L N_h CV_h (1-\hat{\rho}_h^2 (1-\lambda_{opt_h}))^{\frac{1}{2}} \sqrt{c_h}} \quad \text{eq. 1. 10}$$

expressing S_h in terms of the coefficient of variation, CV_h , and noting

C = total snow survey budget for estimation of snow water content in the watershed of interest including both direct and indirect costs,

c_o = total indirect cost portion of budget, C , for snow water content estimation in the watershed of interest, and

$c_{direct} = C - c_o$ = total direct cost portion of budget, C , available for snow water content sample unit measurements in the watershed of interest.

Equation 1.10 is applicable to weighting option 2, while the appropriate substitution of \hat{X}_h for N_h gives the derivation for n_{total} in the case of W01, viz:

$$n_{total} = \frac{(C-c_o) \sum_{h=1}^L (\hat{X}_h CV_h (1-\hat{\rho}_h^2 (1-\lambda_{opt_h}))^{\frac{1}{2}} / \sqrt{c_h})}{\sum_{h=1}^L (\hat{X}_h CV_h (1-\hat{\rho}_h^2 (1-\lambda_{opt_h}))^{\frac{1}{2}} \sqrt{c_h})} \quad \text{eq. 1.11}$$

Ground sample sizes may then be calculated for each stratum according to

$$n_h = (n_{\text{total}})(\lambda_{\text{opt}_h}) \left(\frac{n_h}{n_{\text{total}}} \right) . \quad \text{eq. 1.12}$$

For optimum image-ground sampling rates the number of image sample units per stratum is then given by

$$n'_h = (n_h) \left(\frac{1}{\lambda_{\text{opt}_h}} \right) . \quad \text{eq. 1.13}$$

The total estimated direct cost of snow water content measurement for the watershed of interest will then be

$$\begin{aligned} c_{\text{direct est.}} &= \sum_{h=1}^L (n_h c_{n_h} + n'_h c_{n'_h}) \\ &= \sum_{h=1}^L c_{\text{direct est.}_h} . \end{aligned} \quad \text{eq. 1.14}$$

However in most cases, due to the relationship between equations 1.6 and 1.13, $c_{\text{direct est.}}$ will exceed the given c_{direct} . Thus the number of ground and image sample units must be adjusted downward so that $c_{\text{direct est.}}$ and c_{direct} will be equal. This adjustment is performed by calculation of

$$c_{\text{dif.}} = c_{\text{direct est.}} - c_{\text{direct}} \quad \text{eq. 1.15}$$

and determining the proportion of the total direct cost residing in a given stratum,

$$c_{\text{prop}_h} = \frac{c_{\text{direct est.}_h}}{c_{\text{direct est.}}} . \quad \text{eq. 1.16}$$

Then the sample size reduction factor, K_{r_h} , to apply to both n_h and n'_h for a given h is

$$K_{r_h} = (c_{prop.}_h)(c_{dif.})(c_{dif.}/c_{direct}) \quad \text{eq. 1.17}$$

In some instances the calculated image sample unit size, n'_h , may exceed the total number of possible sample units, N_h , in a given stratum. When this occurs n'_h must be set equal to N_h and λ_{opt_h} reset to n_h/N_h . The money saved

$$c_{save_h} = (n'_h - N_h)(c_{n'_h}) \quad \text{eq. 1.18}$$

is then reallocated to other strata not having n'_h exceed N_h . This may be done by calculating

$$c'_{direct\ est.} = \sum_{(h \in D)} c'_{direct\ est.}_h = \sum_{(h \in D)} c_{direct\ est.}_h - c_{save_h} \quad \text{eq. 1.19}$$

for all strata having n'_h exceed N_h (comprising set D) and obtaining

$$c'_{direct} = c_{direct} - c'_{direct\ est.} \quad \text{eq. 1.20}$$

Then new n_h and n'_h are calculated with the new direct budget, c'_{direct} , for those strata not belonging to set D. In this way n_h and n'_h are obtained by an iterative application of boundary conditions and associated adjustment procedures.

A final sample size correction is appropriate to the snow water content estimation procedure. Since it is specified that all image sample units in a given stratum be examined, the additional cost over the optimum n'_h sample size,

$$c_{additional}_h = (N_h - n'_h)(c_{n'_h}), \quad \text{eq. 1.21}$$

must be taken into account. The procedure utilized consists of adjusting downward the corresponding ground sample size, n_h , for the stratum of interest. Thus

$$n_h = n_h - ((n_h) (\frac{c_{\text{additional } h}}{c_{n_h}})) . \quad \text{eq. 1.22}$$

After final calculation of n_h and n'_h , we may proceed to determine the expected precision of the final watershed snow water content estimate. It is first necessary to calculate an expected overall measure of that estimate's variability. From Thomas (1974)

$$\begin{aligned} \hat{V}(\hat{\bar{Y}}_{\text{total}}) &= \sum_{h=1}^L (w_h)^2 \frac{1}{n_h} \hat{S}_h^2 (1 - \hat{\rho}_h^2 (1 - \lambda_{\text{opt } h})) \\ &\quad - \sum_{h=1}^L (w_h)^2 \frac{1}{N_h} \hat{S}_h^2 (1 - \hat{\rho}_h^2 (1 - \lambda_{\text{opt } h})) \end{aligned} \quad \text{eq. 1.23}$$

where $\hat{V}(\hat{\bar{Y}}_{\text{total}})$ = the estimated variance of $\hat{\bar{Y}}_{\text{total}}$

w_h = a stratum weight

and the last sum on the right represents the finite population correction.

Expressing equation 1.23 in terms of the coefficient of variation we have

$$\begin{aligned} CV_{\text{overall}}^2 &= \sum_{h=1}^L (w_h)^2 \frac{1}{n_h} (CV_h^2 (1 - \hat{\rho}_h^2 (1 - \lambda_{\text{opt } h}))) \\ &\quad - \sum_{h=1}^L (w_h)^2 \frac{1}{N_h} (CV_h^2 (1 - \hat{\rho}_h^2 (1 - \lambda_{\text{opt } h}))) \end{aligned} \quad \text{eq. 1.24*}$$

*Eq. 1.24 will give a slightly higher resulting AE for W01 and a lower AE for W02 than eq. 1.23 due to the relation:

$$CV_{\text{oa}}^2 = \sum (w_h)^2 CV_h^2 = \sum w_h^2 \frac{V(\bar{y}_h)}{\bar{y}_h^2} \neq \frac{\sum w_h^2 V(\bar{y}_h)}{(\sum w_h \bar{y}_h)^2}$$

where $\bar{y}_{\text{st}} = \sum w_h \bar{y}_h$, $V(\bar{y}_{\text{st}}) = \sum w_h^2 V(\bar{y}_h)$.

For stratum weighting option 1

$$w_h = \frac{\hat{x}_h}{\sum_{h=1}^L \hat{x}_h} \quad \text{eq. 1.25}$$

and for stratum weighting option 2

$$w_h = \frac{N_h}{\sum_{h=1}^L N_h} \quad \text{eq. 1.26}$$

Then if precision is defined in terms of allowable error, AE, we have
for a given budget structure

$$AE = (t_{n_{\text{total}}-1}) CV_{\text{overall}} \quad \text{eq. 1.27}$$

where

$t_{n_{\text{total}}-1}$ = Student's-t with $n_{\text{total}}-1$ degrees of freedom
corresponding to a chosen level of confidence, $1-\alpha$, and

AE = the half-width of an interval, usually expressed
as a percentage of the estimated value, in which
the actual watershed snow water content is said
to lie with probability $1-\alpha$.

APPENDIX II - STATISTICS USED IN THE CALCULATION OF SAMPLE SIZES AND
ALLOWABLE ERRORS FOR THE REMOTE SENSING-AIDED SNOW WATER
CONTENT ESTIMATION SYSTEM

Table 11.1 gives the results for LANDSAT snow water content statistics based on Spanish Creek Watershed data. These statistics are used to represent Feather River Basin values due to the similarity in snow water content class distribution between the two basins for the snow season dates investigated.

Table 11.2 gives the LANDSAT snow areal extent and resulting snow water content indices corresponding to ground data for the Feather River Watershed. The resulting correlation between ground (y_{ave}) and X_3 is 0.85, between y_{ave} and X_3 , is 0.80, and between y_{ave} and X_2 is 0.77. Since more than two dates will be available in most operational snow water content estimation situations, a conservative value of 0.80 was selected as the correlation coefficient to be used in the sample size analysis. Correlation coefficients could not be calculated individually for all strata. This situation resulted from the lack of adequate degrees of freedom for snow courses falling in individual LANDSAT snow water strata. Examination of several months of data may allow stratum specific correlation coefficients to be calculated.

The above CV_h , \hat{X}_h , W_h , N_h , and $\hat{\rho}_{X_3, y_{ave}}$ statistics were substituted into formulas given in Appendix I to calculate ground and image sample sizes. These figures were also used to calculate the overall basin coefficient of variation, $CV_{overall}$, used in determining allowable error for the basin estimate of total snow water content.

TABLE 11.1 - LANDSAT SNOW WATER CONTENT STATISTICS BASED ON SPANISH CREEK WATERSHED DATA FOR APRIL 4, MAY 10, AND MAY 28, 1974

Stratum Index (h)	LANDSAT Snow Water Content Estimate Range	Ave. Snow Water Content Index Per Image Sample Unit $\bar{X}_h = \frac{\sum_{i=1}^{I_h} X_{hi}}{I_h}$	Standard Deviation For X_{hi} σ_h	Coefficient of Variation $CV_h = \frac{\sigma_h}{\bar{X}_h} \times 100$	Total Snow Water Content Index $X_h = \sum_{i=1}^{I_h} X_{hi}$	Stratum Weight Based on Snow Water Content $W_h = \frac{X_h}{\sum_{i=1}^6 X_h}$	Number of Image Sample Units for the Spanish Creek Watershed N_h^*	N_h^*/N^*	Number of Image Sample Units For the Feather River Watershed $N_h = 2,218 \left(\frac{N_h^*}{N^*} \right)$
1	0.00-<0.10	0.0000	0.0000	0.00	0.00	0.0000	32	0.2270	503
2	0.10- 0.35	0.1833	0.1194	65.14	7.15	0.0304	39	0.2766	614
3	<0.35-<1.00	0.7808	0.1883	24.12	10.15	0.0432	13	0.0922	205
4	1.00-<3.00	2.0480	0.4404	21.50	51.20	0.2178	25	0.1773	393
5	3.00- 5.00	3.9557	0.4525	11.44	55.38	0.2356	14	0.0993	220
6	>5.00	6.1750	0.9672	15.66	111.15	0.4729	18 $N^*=141$	0.1277	<u>283</u> $N=2,218$

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CCSS Snow Course Index (i)	ERTS ISU Snow Areal Extent Data Corresponding to Snow Course Location ²						Intermediate Statistics				Resulting Snow Water Content Indices			Average April-May Snow Water Content in Inches of Water as Determined From CCSS Ground Survey Measurements ³ (\bar{y}_{ave})	The Resulting Correlations Between ERTS and Ground Snow Water Content Measures:
	Snow Class (Date 1)	Midpoint S_{11}	Snow Class (Date 2)	Midpoint S_{21}	Snow Class (Date 3)	Midpoint S_{31}	$M_{21} = \sum_{j=1}^2 \text{snow-class } j = 1 \text{ midpoints}$ $= \sum_{j=1}^2 S_{j1}$	$M_{31} = \sum_{j=1}^3 \text{snow-class } j = 1 \text{ midpoints}$ $= \sum_{j=1}^3 S_{j1}$	$K_{21} = \text{Number of times corresponding ISU had snow class } > 1 \text{ for } j=1,2$	$K_{31} = \text{Number of times corresponding ISU had snow class } > 1 \text{ for } j=1,2,3$	$X_{31} = (M_{31})/(K_{31})$ Based on: 3 dates snow class 3 dates snow presence/absence	$X_{21} = (M_{21})/(K_{21})$ Based on: 2 dates snow class 2 dates snow presence/absence	$X_{11} = (M_{11})/(K_{11})$ Based on: 1 date snow class 1 date snow presence/absence		
47	5	.99	5	.99	5	.99	1.98	2.97	2	3	8.91	5.94	3.96	83.30	$\rho_{x_3, \bar{y}_{ave}} = 0.85$
49	5	.99	5	.99	3	.35	1.98	2.33	2	3	6.99	5.94	3.96	73.30	
54	5	.99	5	.99	4	.74	1.98	2.72	2	3	8.16	5.94	3.96	51.75	
53	5	.99	4	.74	2	.10	1.73	1.83	2	3	5.49	5.19	3.46	49.95	$\rho_{x_3, \bar{y}_{ave}} = 0.80$
279	5	.99	5	.99	4	.74	1.98	2.72	2	3	8.16	5.94	3.96	47.15	
56	5	.99	3	.35	1	.00	1.34	1.34	2	2	2.68	2.68	2.68	38.80	
52	5	.99	4	.74	3	.35	1.73	2.08	2	3	6.24	5.19	3.46	34.45	$\rho_{x_2, \bar{y}_{ave}} = 0.77$
360	5	.99	4	.74	1	.00	1.73	1.73	2	2	3.46	3.46	3.46	29.50	
51	5	.99	5	.99	2	.10	1.98	2.08	2	3	6.24	5.94	3.46	26.85	
359	5	.99	2	.10	1	.00	1.09	1.09	2	2	2.18	2.18	2.18	26.20	$\rho_{x_2, \bar{y}_{ave}} = 0.77$
48	5	.99	3	.35	2	.10	1.34	1.44	2	3	4.32	4.02	2.68	26.00	
55	5	.99	3	.35	1	.00	1.34	1.34	2	2	2.68	2.68	2.68	25.10	
58	5	.99	3	.35	2	.10	1.34	1.44	2	3	4.32	4.02	2.68	23.80	$\rho_{x_2, \bar{y}_{ave}} = 0.77$
230	5	.99	4	.74	1	.00	1.73	1.73	2	2	3.46	3.46	3.46	16.75	
280	5	.99	3	.35	1	.00	1.34	1.34	2	2	2.68	2.68	2.68	13.25	
355	4	.74	1	.00	1	.00	.74	.74	1	1	.74	.74	.74	6.70	$\rho_{x_2, \bar{y}_{ave}} = 0.77$
354	3	.35	1	.00	1	.00	.35	.35	1	1	.35	.35	.35	3.70	
353	4	.74	1	.00	1	.00	.74	.74	1	1	.74	.74	.74	1.30	

1. Ground-image sample unit spatial matching was based on the best published data (Bulletin 129). CCSS has recently plotted their Feather River Watershed snow courses on 15 minute USGS quadrangles and these data will be used to check the previous ground ERTS sample unit registration.

2. Date 1 = April 4, 1973; Date 2 = May 10, 1973; Date 3 = May 28, 1973.

3. Snow water content measured near the first of each month.

TABLE 11.2 - LANDSAT (formerly ERTS) SNOW AREAL EXTENT DATA AND RESULTING SNOW WATER CONTENT INDICES FOR THE IMAGE SAMPLE UNITS (ISU's) TENTATIVELY¹ LOCATED OVER AREAS IN WHICH CORRESPONDING SNOW COURSES EXIST FOR THE FEATHER RIVER WATERSHED, CALIFORNIA

APPENDIX III - DETERMINATION OF ALLOWABLE ERROR FOR CCSS SNOW COURSE DATA

Ideally, two or more LANDSAT survey dates before a snow prediction date are desirable for high LANDSAT to ground snow water content correlations. In such a situation, LANDSAT snow water estimates using equation 4.1 would be made for the date of interest. A direct comparison would be made for ground data of that date. However, interpreted LANDSAT snow areal extent data were not available to this study for an additional month preceding April 1973. Therefore the average of CCSS April and May 1st snow water content values was chosen as the ground data against which to compare corresponding LANDSAT estimates.

The California Cooperative Snow Survey's snow course data for the Feather River Basin are given in Table III.1. Snow water content information for April and May 1973 is listed along with the average values for the two dates. The second column from the right gives the average values sorted highest to lowest. These are in turn sorted into ranges based on LANDSAT snow water content strata proportions.

In order to calculate a basin snow water content allowable error, a coefficient of variation (CV) among snow courses must be determined. This operation can be performed if it is assumed that the snow courses are randomly allocated to image sample units throughout the Feather River Watershed. This assumption was justified in section 4.2.2.3. It actually favors performance of the CCSS model, since the courses are actually not allocated to all areas of the watershed. Thus they do not sample completely snow water content variability within a basin. However,

TABLE III.1 - CCSS SNOW COURSE DATA FOR APRIL AND MAY 1973

CCSS Course Index (i)	April SWC* Y_{A_i}	May SWC Y_{M_i}	Average of April and May SWC Y_{ave_i}	Simulated LANDSAT Stratum No.
47	84.0	82.6	83.30	6
49	76.7	69.9	73.30	6
54	56.0	47.5	51.75	6
53	55.0	44.9	49.95	5
279	52.9	41.4	47.15	5
56	46.5	31.1	38.80	5
395	47.6	36.0	36.80	5
52	41.3	27.6	34.45	5
360	37.2	21.8	29.50	4
51	31.2	22.5	26.85	4
359	33.2	19.2	26.20	4
48	28.2	23.8	26.00	4
55	28.9	21.3	25.10	4
58	30.2	17.4	23.80	4
361	24.6	12.8	18.70	4
290	21.3	12.2	16.75	4
280	17.6	8.9	13.25	4
355	13.4	0.0	6.70	3
394	12.2	0.0	6.10	3
354	7.4	0.0	3.70	3
353	2.6	0.0	1.30	2
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	n = 21	21	21	
	$\bar{y} = 35.62$	25.28	30.45	
	$\hat{\sigma} = 21.39$	22.07	21.61	
	$CV = \frac{\hat{\sigma}}{\bar{y}} \times 100 = 60.05$	87.31	70.96	

*Footnote: SWC = Snow Water Content in Inches

as was also pointed out in the text, it is not the present intent of the snow course network to sample all snow water content strata in a complete fashion.

After assuming simple random sampling, the coefficient of variation is calculated for each snow data set by determining the sample standard deviation, dividing it by the sample mean and multiplying the result by 100. These statistics are generated at the bottom of Table III.1 for the April, May, and average snow water content data sets.

As seen in Table III.1, the resulting CV for the averaged data set is 70.96 percent. This value can be adjusted by the finite population correction

$$f_{pc} = \frac{N-n}{N} = \frac{2218-21}{2218} = .9905 \quad \text{eq. III.1}$$

where N = total number of image sample units in a basin, and
 n = total number of image sample units ground sampled,
to give a corrected CV of 70.29 percent.

The calculated CV is substituted into equation 4.2 to give an allowable error figure. This allowable error value may then be directly compared to the AE results for the LANDSAT weighting option 2 method. On the other hand, to compare weighting option precision figures to CCSS AE values requires an additional consideration. For strict statistical comparability (based on Cochran 1963), a weighting of the snow course observations similar to that performed on LANDSAT strata is necessary. This amounts to treating the CCSS sample as one selected with probability proportional to the water content size

of the LANDSAT stratum in which they would be expected to fall. The estimated variance for such a sample would then be (based on Cochran 1963)

$$\hat{V}(\hat{\bar{Y}}_{pps}) = \frac{1}{nM_o} \sum_{h=1}^6 \sum_{i=1}^{I_h} M_{hi} (\bar{y}_{hi} - \hat{\bar{Y}})^2 \quad \text{eq. III.2}$$

where

$$M_o = \sum_{h=1}^6 \sum_{i=1}^{I_h} M_{hi},$$

$M_{hi} = X_h$ = total snow water content index for stratum h based on LANDSAT data,

n = sample size (no. of snow courses),

I_h = number of snow courses falling in snow water content strata h as determined from Table III.1,

\bar{y}_{hi} = estimated snow water content value for snow course i of stratum h, and

$\hat{\bar{Y}}$ = estimated mean snow water content of all snow courses for the sample, defined here as the mean of the averaged snow water content ground values.

Substitution of the appropriate data into equation III.2 allows the calculation of a CV of 17.64 percent. Adjustment for the finite population correction gives 17.47 percent. This value may then be used in equation 4.2 to generate AE figures which can be compared to the results of the LANDSAT weighting option 1 method.

The sensitivity of the CV calculated via equation III.2 to a change in data assumptions should be examined. This analysis is relevant here

since the proportion of snow courses in a given LANDSAT stratum range does not in fact match the proportion defined for the watershed according to data given in Appendix II. That is, probability proportional to estimated size sampling would not likely result in the snow course set currently operated by the CCSS.

Table III.2 summarizes the CCSS and LANDSAT strata size proportions based on the number of ground and image samples respectively falling in various strata. The LANDSAT proportions show the $h=6$ and $h=5$ case. The stratum size 5 ($h=5$) case was included to determine changes in calculated CV if the first LANDSAT stratum were dropped. The ratios of LANDSAT to ground strata proportions are shown in the two right-most columns. Applying these ratios, or relative stratum size correction factors, to formula III.2 then gives a measure of sensitivity of the calculated CV to LANDSAT-CCSS stratum size inconsistencies.

The result of the sensitivity analysis is that for $h=6$ the CV drops approximately 1% relative to the previous calculated value. For $h=5$, the CV rose on the order of 1%. Due to the small offsetting changes, the originally calculated CV value, 17.47 percent, is utilized for AE calculations in this study.

TABLE III.2 - CCSS AND LANDSAT SYSTEM STRATA SIZE PROPORTIONS

CCSS			LANDSAT				Stratum Size Proportion Ratios	
h	$n_h^{(1)}$	$\frac{n_h}{n} = R_{CCSS}$	$n_h^{(2)}$	$\frac{n_h}{n} = R_{LANDSAT_1}$	$n_h^{(3)}$	$\frac{n_h}{n} = R_{LANDSAT_2}$	$R_1 = \frac{R_{LANDSAT_1}}{R_{CCSS}}$	$R_2 = \frac{R_{LANDSAT_2}}{R_{CCSS}}$
1	0	0.0000	32	0.2270	---	---	---	---
2	1	0.0476	39	0.2766	39	0.3578	5.8109	7.5168
3	3	0.1429	13	0.0922	13	0.1193	0.6452	0.8348
4	9	0.4286	25	0.1773	25	0.2294	0.4137	0.5352
5	5	0.2381	14	0.0993	14	0.1284	0.4171	0.5393
6	3	0.1429	18	0.1277	18	0.1651	0.8936	1.1554
Σ	21	1.0001	141	1.0001	109	1.0000		

1. For entire Feather River Basin.
2. Spanish Creek Watershed data: Distribution of snow classes assumed approximately equal to the Feather River Basin distribution.
3. Spanish Creek Watershed data omitting stratum 1.

CHAPTER 7

ERTS* AS AN AID IN TIMBER VOLUME INVENTORY

A Special Presentation to Office of
Applications, NASA Hdqts. Funded under
NASA Grant No. NGL05-003-404

26 August 1974

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*"ERTS" is now called "LANDSAT," but the term "ERTS"
is retained here to agree with this material as
already distributed and cited.

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CHAPTER 7

TABLE OF CONTENTS

		<u>Page</u>
7.00	Introduction J. D. Nichols	7-1
7.10	The Need for Timber Volume Surveys D. T. Lauer	7-3
	7.11 Volume Surveys within the United States	7-3
	7.12 Volume Surveys outside the United States	7-4
7.20	Description of Multistage Variable Probability Sampling for Timber Volume Estimation J. D. Nichols and M. Gialdini	7-6
	7.21 Method of Estimation	7-6
	7.22 Variance of the Estimation	7-12
7.30	Comparison of the Cost Effectiveness of an ERTS Based Timber Volume Inventory and a Conventional Timber Volume Inventory B. Orme	7-16
	7.31 Assumptions	7-17
	7.32 Economic Theory	7-17
	7.33 Results and Conclusions	7-18
7.40	The Future of Human-Computer Processed ERTS MSS Data in Resource Inventory, Mapping and Assessment J. D. Nichols	7-25

7.00 INTRODUCTION

Under some rather broad guidelines as set forth in our ERTS-1 contract the Remote Sensing Program investigated the utility of ERTS to provide useful information for wildland resource management. To investigate the information content of the ERTS data we used both human and computer discriminant analysis techniques to extract information from raw photographic data, color enhanced data and computer compatible tapes. Early in the investigation we determined that the human could delineate general vegetation types in environmentally similar areas using the raw bulk color composite images. We also determined that the computer could identify, down to the plant community level, species composition, stand density and some stand condition information. It became apparent that the ERTS data could not meet all of the wildland resource manager's needs, but that it could provide a basis for sampling the wildland environment. From this basic research the Remote Sensing Research Program at the University of California began to develop techniques to utilize the information available from the ERTS satellite in multistage sampling schemes.

By March 1973 progress had been made to the point where discriminant analysis could be made at the plant community level, delineation of large environmental areas could be made to control a discriminant analysis procedure, multistage sampling strategy and estimation procedures had been developed, large scale photographic capabilities were available, and user requirements had been defined. The information requirements had been determined for forestry, range, land use, recreation, engineering and land use planning.

Due to time constraints on our ERTS-1 study, it was decided that only a single-parameter inventory could be concluded within the contract limitations. Based on the work completed by Langley under the Appollo program and the fact that one of the single most important parameters to the forest manager, timber industry, and resource policy maker is saleable timber volume, this was the single parameter selected for inventory and assessment.

The results which we obtained in the Plumas National Forest, Quincy Ranger District timber volume inventory were encouraging. The variance of the final estimate was reduced far below the expected value and sample size was reduced as a result of this. The ERTS data contributed to the overall success of the inventory by providing a quick, consistent, and inexpensive means of providing the first stage work for allocating samples and providing initial estimates of timber volume. It also provided a unique new type of information. This was the "in-place" mapping of the wildland vegetation which allowed a much more efficient allocation of samples than had ever before been possible. After the timber volume inventory was completed, it was even more apparent that there was

information contained in the ERTS data far beyond the "timber volume only" information that was estimated and confirmed by the original inventory.

As a result of the study and the presentation at the ERTS program review, the Remote Sensing Program's timber inventory study was considered to be nearly operational and follow-on funding was provided. The objective of the extension study was to complete the timber volume inventory and expand it to a total timber resource inventory at the management level. Working with the people from the U.S. Forest Service on the Plumas National Forest, further definition of the overall needs for timber resource information was obtained and a sampling scheme developed to utilize, as fully as possible, the ERTS multispectral scanner data as processed in the discriminant analysis routines. The final field work was completed on September 28, 1974 and the data analysis is now in progress to complete this total timber resource inventory.

As a result of the success of the timber volume study and the work being conducted this year for the total timber resource, the Remote Sensing Program was asked to provide this report on the cost-effective information regarding the timber volume study and as a follow-on, to determine the cost benefit and cost effectiveness of the total timber resource inventory being completed this summer under ERTS extension funding.

7.10 THE NEED FOR TIMBER VOLUME SURVEYS

Sound forest management practices are dependent upon the availability of accurate, timely and economical forest inventory data, which includes timber inventory volume surveys. Forest inventory requirements in the intensively managed temperate regions of the world include data not only on timber volume but also on timber stand condition, ownership, soils, bedrock geology, surface geology, mineral extraction, subsurface water, surface water, vegetation, wildlife, land use, land productivity, climate, historical and cultural patterns, population, market values, and transportation. However, 28% of the world's land area is covered by forest, containing some 12½ trillion cubic feet of timber. Only a small portion of this vast area is intensively managed. Within the non-intensively managed or unmanaged forests, low-cost "volume only" surveys are needed, as man for the first time finds it possible to start placing these forests under management.

7.11 Volume surveys within the United States

In 1970 the annual demand for timber in the United States reached a level of 56 billion board-feet of which 8% was imported. The National Commission on Materials Policy reported in August, 1973 that by the year 2000 annual supplies of both hardwood and softwood would fall short of projected annual demand by about 20 billion board-feet.

In April, 1973 the President's Advisory Panel on Timber and the Environment reported that the current trend in application of the Forest Service timber management planning guidelines on each national forest indicates that the Forest Service will be unable to respond with any significant increase in timber supply (allowable cut) from national forests during the coming decade. Consequently, the nation's increasing demand for timber will be met mainly through increased imports, increased utilization of wood materials currently being harvested and increased utilization of forest lands currently considered marginal for purpose of timber production. Timber volume surveys are needed within these marginal lands since little or no inventory information exists. Vast acreages of Pinon-Juniper forest in the western U.S. are increasingly being used for charcoal production and are being considered as a source of pulpwood, fuelwood, fence posts, and Christmas trees. Likewise, unsurveyed stands of Oak are being used by the furniture, packing and pulp industries, and Eucalyptus is beginning to be utilized for pulp and paper. Bottomland hardwood forests in the Southern U.S. and low-density, low volume softwood stands in Alaska are additional sources of cellulose available for meeting the increase in demand for wood, but for the most part, these forests have never been adequately surveyed in terms of timber volume.

Nevertheless, the U.S. will probably rely more heavily on tropical forests for meeting future demands. The Forest Service reported in the publication entitled "The Outlook for Timber in the U.S.," updated October, 1973, that in spite of growing world demands for timber products, potential increased harvests in Canada and the tropics should meet U.S. import requirements.

C-6

7.12 Volume surveys outside the United States

By the year 2000 total world wood consumption will double -- with the largest increases occurring in wood used for pulp. It was noted by the Secretariat for Commission VI of the 7th World Forestry Congress in October, 1972 that world supplies can meet this increased demand as long as exports can be expanded. However, it was pointed out by the National Commission on Material's Policy in August, 1973 that:

"the optimistic views about growing demand for wood and the ability of the world's forests to meet the demand are clouded by lack of adequate inventories, appraisals and plans for much of the forested areas of the world."

Without a doubt, the greatest need for regional forest volume surveys today is in the relatively less developed tropical regions of the world, including much of Central America, northern and central South America, central Africa, and Southeast Asia. It has been estimated that the tropical forests in these areas comprise approximately 40% of the world's total forest area. Latin America, for example, with its vast reserves, harvested less than 4% of the world's industrial wood during the period 1967-69.

The need for forest surveys in tropical regions stems from a combination of several interrelated factors. Many of the countries in these areas are not highly industrialized, many are not rich in sources of foreign exchange, and in many cases do not possess an abundance or diversity of natural resources. However, in many cases they do have potentially valuable forest resources and relatively inexpensive sources of labor. Thus the forest represents a possible source of material for export, if there is foreign capital for internal development. Also, as industrialization grows and populations increase, there is often a critical need for raw materials for construction and fuel. This is complicated by the fact that in many tropical countries tremendous areas of forest are converted to agriculture (it has been estimated that in Latin America alone, 5 to 10 million hectares of forest land are cleared annually for agriculture).

It is apparent that there exists a critical need for rational, far-sighted development of forests in the less developed tropical regions as opposed to the haphazard liquidation of the resource that has so often occurred. As all foresters know, one of the first requirements for orderly forest management is an accurate, timely inventory of the extent, location, and quality of the resource. Useful forest inventories are lacking, however, in many less-developed countries.

The difficulty of obtaining forest inventories by means of conventional techniques is greatly complicated by variations in the composition of the forests themselves, and the attributes of the regions in which they occur. In many cases tropical forests are composed of a mixture of dozens or even hundreds of species, only 10% or so of which may be commercially valuable for lumber. Before significant investment is made in developing the necessary transportation and processing facilities, it is necessary to know where the greatest volumes of the more valuable species exist. Because the inventory often entails the estimation of proportions of species in various forest types rather than the more simple measurement of relatively pure stands as occur in more temperate regions, forest inventories in tropical regions present some rather unique and as yet unsolved problems in technique.

Finally, the fact that many tropical forest regions are virtually inaccessible on the ground presents serious problems in the implementation of conventional inventory techniques. The cost of getting a man to a ground plot, if possible at all, may be extremely expensive and time consuming. Thus, techniques utilizing ERTS and aircraft data which reduce the number of ground plots may prove to be particularly useful and cost effective in the tropics.

Unlike other timber volume inventory procedures, an ERTS based inventory provides an in-place mapping and estimate of volume by type of the resources with a confidence statement about the accuracy of that estimate. With this information the monitoring of the effect of disaster is more easily handled. If a disaster such as fire, flood, landslide, avalanche, tornado, typhoon, hurricane or insect/disease attack should occur, the area affected can be analyzed using ERTS data on the before and after basis. Estimates of the new total can then be made and the damage evaluated.

An example of where a low-cost ERTS-based survey could have been employed, had it been available, is the insect infestation problem which recently occurred in Honduras. The pine and pine-hardwood forests in Honduras are found on more than 27,000 km² of land containing some 134 million m³ of timber. Since most of the land in Honduras is too mountainous for agricultural uses, the expanding population, expected to reach nearly 2 million people by 1984, is dependent mainly on timber production for providing work and wages. In 1962 a bark beetle epidemic occurred, caused by unknown reasons. By 1964 more than 5,000 km² were affected and not until August, 1965 had the infestation lost its epidemic character. Surveys subsequent to the epidemic showed that the average loss of pine volume to the bark beetle had been 20%. At 1964 prices, Honduran pine lumber brought an average of \$36 per cubic meter on the export market. If all the volume of pine lost in the epidemic had been cut and sawn into lumber, the exportable portion would have brought Honduras more than 300 million dollars in revenue -- nearly 75% of the GNP for the entire country in 1964.

Obviously this national disaster, like hundreds of others that could be cited here, greatly affected the economic and social stability of the country in which it occurred. Likewise, with an ever expanding dependence of the U.S. on imported wood supplies, the future effects of these disasters on quantity, quality and prices of world wood supplies will without a doubt become increasingly critical. Consequently, not only will developing nations want to inventory and monitor catastrophic events occurring in their own forests, but also the U.S. will want to keep a watchful eye on these occurrences.

In summary, in terms of the utilization and management of raw materials from the forested areas of the world, regional "volume only" estimates have limited but valuable applications. These applications mainly are surveys of marginal forest lands within the U.S., surveys of tropical forests and surveys of the effects of catastrophic events occurring in forested areas throughout the world.

DESCRIPTION OF MULTISTAGE VARIABLE PROBABILITY SAMPLING FOR TIMBER VOLUME ESTIMATION

Variable probability sampling methods which are employed to estimate total timber volume utilize three variables proportional to timber volume in generating the selection probabilities: (1) "volume" estimates of the ERTS picture elements based on the spectral signatures on four bands and subsequent training and classification; (2) volume estimates of plots on 1:1,000 scale color prints, based on local photo-volume tables and (3) tree volume estimates from large scale photos, based on crown diameters and tree height estimates.

When this scheme is used, where the probability of selection is proportional to the estimated volume, the effort is focused on the areas of higher timber volume and thus adds to the overall cost-efficiency.

7.21 Method of Estimation

The method of estimation is based on "unequal expansion" as implied by the probability scheme discussed above. At each of the three stages, the probability-proportional-to-estimated-size (p_i) is obtained by listing the volume estimates of the sampling units (x_i), and dividing them by the total

of volume estimates $T_i = \sum_{i=1}^n x_i$. Thus, $p_i = \frac{x_i}{\sum_{i=1}^n x_i}$.

A sample of a chosen size is then drawn by applying random integers from 1 to T_i and observing the probability interval and the corresponding sampling unit which contains the randomly selected integers (see Table III).

STAGE I Classification of ERTS-1 Data and Primary Sample Unit Selection

ERTS data tapes of the area are classified using a supervised classifier such as the CALSCAN* point-by-point maximum likelihood classification routine. The coordinates of administrative boundaries and of broad vegetation types are identified

*CALSCAN is the RSRP version of the LARS-Purdue pattern recognition program adapted to the CDC 6600/7600 system at the University of California, Berkeley.

TABLE III EXAMPLE OF SAMPLE UNIT SELECTION WITH PROBABILITY-PROPORTIONAL-TO-ESTIMATED-SIZE (PPES). SAMPLE UNIT 4 WAS SELECTED BY

DRAWING A RANDOM INTEGER (313) BETWEEN 1 AND $T_c = \sum_{i=1}^n x_i = 10000$.

POPULATION OF SAMPLE UNITS	ESTIMATED SIZE OF SAMPLE UNIT	CUMULATIVE TOTAL OF ESTIMATES	PROBABILITY OF SELECTION
i	x_i	$\sum_{i=1}^n x_i$	$p_i = \frac{x_i}{\sum_{i=1}^n x_i}$
1	120	120	120/10000=0.0120
2	73	193	73/10000=0.0073
3	27	220	27/10000=0.0027
4	115	335 ¹	115/10000=0.0115
5	66	401	66/10000=0.0066
6	90	491	90/10000=0.0090
.	.	.	.
.	.	.	.
.	.	.	.
n	48	$T_c = 10000$	48/10000=0.0048

1 Sample unit 4 is included in the sample resulting from drawing random integer 313.

2 T_c = Cumulative total of all sample unit estimates in the population.

on the tapes so that only those picture elements associated with forest land are classified and incorporated into the inventory. This stratification procedure considerably reduces the costs of classification and is required for administrative purposes.

Classification should be based on a small number of timber volume classes, for example (1) non-forest; (2) forest sites containing less than 10,000 board feet per acre (bd ft/ac); (3) forest sites containing 10,000 to 20,000 bd ft/ac, and (4) forest sites containing more than 20,000 bd ft/ac. The classifier is trained to recognize each of the timber volume classes based upon photo interpreter selection of training cells according to tree crown closure and average crown diameter (or other variables related to volume for the study area). The training cells can be selected from interpretation of existing resource photography from scales of 1:15,840 to 1:130,000. Each of the training cells is located on the ERTS digital tapes. Point-by-point classification of all ERTS data points within the area proceed by assigning each data point (picture element) to a training class that it most nearly matches. The results are grouped into the selected timber volume classes.

The classified data of the area are divided into rectangular sampling units (called primary sampling units). The size of these sampling units is based on (1) a practical area which can be photographed in a single flight line by a light aircraft using a 35 mm camera system, (2) the ability of the ground crew to complete the ground work for a flight line in one day, (3) the variation between SU's. and (4) the ability to transfer the PSU's to a photo or map base.

For each primary sampling unit, the following information is computed:

1. The number of points in each volume class (within the unit).
2. The weighted total volume for each volume class (estimated size).
3. The sum of the weighted totals for all classes.
4. A cumulative sum of the weighted totals.
5. The mean volume for the sampling units.
6. The variance of the sampling units.

A sample of n_h out of the N_h PSU's is then drawn from administrative-general vegetation type stratum h with probability proportional to estimated size (ppes) of timber volume. The locations of the selected PSU's are transferred from the ERTS classified and raw images to aerial photography (and maps) to facilitate locating them accurately from the air when they are photographed from a lower altitude as part of the second stage of the timber inventory.

The estimate of the total volume then becomes:

$$\hat{V} = \sum_{h=1}^L \frac{1}{n_h} \sum_{i=1}^{n_h} \frac{y_{hi}}{p_{hi}}$$

where: L = total number of administrative-general vegetation type strata

p_{hi} = selection probability of the i^{th} PSU in the h^{th} stratum

y_{hi} = total volume of the i^{th} PSU in the h^{th} stratum (remains to be estimated by subsequent stages).

Stage II Volume Estimation on Low Altitude Photography

Two 35 mm or 70 mm cameras are then used to obtain low altitude photography of the selected primary sampling units at two different scales. A short focal length, wide-angle lens is used to acquire complete coverage of each sampling unit at an approximate scale of 1:7,500, and a long focal length is used to obtain large scale stereo triplets, scale approximately 1:1,000, from which to make precise photo estimates of plot and tree volume. The camera with the telephoto lens must be equipped with a motorized film drive to enable each stereo triplet to be taken within one second at five second intervals while the camera with the wide-angle lens can be operated manually to obtain single frames at five second intervals. The photo coverage for each PSU consists of ten stereo triplets and ten wide angle photographs.

The wide-angle photos of each primary sampling unit are mosaicked together to show its full area. The center of the middle photo for each stereo triplet is used as the plot center, and these are located and marked on the mosaic. The plot centers are also located on a topographic map and the elevation of each is determined.

The approximate scale of each photo is then determined, and a circular plot is drawn around the photo plot center. The timber volume in each photo plot is estimated by referring to local photo-volume tables based upon interpretation of percent crown closure and measurement of average stand height using a parallax bar (such as Chapman, 1965 for the Sierras).

To estimate the total volume (y_{hi}) of the i^{th} PSU, a sample of n_{hi} out of the N_{hi} secondary sampling units is drawn with ppes. This gives:

$$\hat{y}_{hi} = \frac{1}{n_{hi}} \sum_{k=1}^{n_{hi}} \frac{y_{hik}}{p_{hik}}$$

However, in order to include area expansion from circular sample plots to the full PSU, and also to stratify the second stage plots into the selected volume strata, the estimator becomes:

$$\hat{y}_{hij} = \sum_{j=1}^J \frac{1}{p_{hij}} \frac{A_{hij}}{a_{hij}} \frac{1}{n_{hij}} \sum_{k=1}^{n_{hij}} \frac{\hat{y}_{hijk}}{p_{hijk}}$$

where: $j = 1, 2, \dots, J$ refers to the CALSCAN volume strata

p_{hij} = selection probability of the j^{th} volume stratum of the i^{th} PSU in the h^{th} stratum

A = area (indexes as above)

a = sampled area (indexes as above)

n = sample size (indexes as above)

p_{hijk} = selection probability of the k^{th} plot of the j^{th} volume stratum, of the i^{th} PSU in the h^{th} stratum

\hat{y}_{hijk} = plot volume (to be estimated by stage III).

STAGE III. Selection of Trees for Precise Ground Measurement of Timber Volume

In the third stage, all trees of merchantable size within each selected photo plot are pin-pricked and numbered. For each of these trees, the average crown diameter is determined based on the longest and shortest dimensions of their crowns and an estimate of tree height obtained from the wide angle photos. After adjustments for scale, the average crown diameter and estimated tree height are used as a relative measure of the merchantable volume of wood in the individual trees. To estimate the total volume of the k^{th} plot, a sample of n_{hijk} out of the N_{hijk} tertiary sampling units (trees) are drawn with pps (using this estimate of tree volume). Then:

$$\hat{y}_{hijk} = \frac{1}{n_{hijk}} \sum_{l=1}^{n_{hijk}} \frac{y_{hijkl}}{p_{hijkl}}$$

where: p_{hijkl} = the selection probability of the l^{th} sample tree of the k^{th} plot of the j^{th} volume stratum of the i^{th} PSU of the h^{th} stratum.

y_{hijkl} = the dendrometer-measured volume of the l^{th} sample tree of the k^{th} plot of the j^{th} volume stratum of the i^{th} PSU of the h^{th} stratum.

A two-man crew with a Barr and Stroud optical dendrometer measures the selected trees. The large scale (low altitude) photographs are used to locate the photo plot centers as well as the trees within the plots to be measured. In addition to the dendrometer measurements, an easily recognizable feature on the ground near the plot center is measured in order to obtain a more accurate estimate of the scale of the photo plot. The dendrometer measurements are entered into a computer program to calculate merchantable stem volumes for the individual trees.

Combining the various stages above, the entire estimator becomes:

$$\hat{V} = \sum_{h=1}^L \frac{1}{n_h} \sum_{i=1}^{n_h} \sum_{j=1}^j \frac{1}{p_{hij}} \frac{A_{hij}}{a_{hij}} \frac{1}{n_{hij}} \sum_{k=1}^{n_{hij}} \frac{1}{p_{hijk}} \frac{1}{n_{hijk}} \sum_{l=1}^{n_{hijk}} \frac{y_{hijkl}}{p_{hijkl}}$$

7.22 Variance of the Estimator

In multistage sampling, when the number of first stage units is large, most of the variability in the population is due to the first stage. Therefore, it suffices to consider only the first stage values (here y_{hi}) to estimate the population variance and, consequently, the variance of the estimator (Durbin, 1953, p. 262; Kendall and Stuart, 1967, vol. 3, p. 200; Langley, 1971, p. 131).

Thus, for the first stage the stratified sampling estimator becomes (Cochran, 1963, p. 260):

$$\hat{V} = \sum_{h=1}^L \frac{1}{n_h} \sum_{i=1}^{n_h} \frac{y_{hi}}{p_{hi}}$$

Its variance is:

$$\text{Var}(\hat{V}) = \sum_{h=1}^L \frac{1}{n_h} \sum_{i=1}^{n_h} p_{hi} \left(\frac{y_{hi}}{p_{hi}} - \hat{V}_h \right)^2$$

which has an unbiased estimator:

$$\hat{\text{Var}}(\hat{V}) = \sum_{h=1}^L \frac{1}{n_h(n_h-1)} \sum_{i=1}^{n_h} \left(\frac{y_{hi}}{p_{hi}} - \hat{V}_h \right)^2$$

For proportional allocation, $n_h = n(N_h/N)$ and

$$\begin{aligned} \text{Var}(\hat{V}) &= \sum_{h=1}^L \frac{N}{n} \sum_{i=1}^{N_h} p_{hi} \left(\frac{y_{hi}}{p_{hi}} - \hat{V}_h \right)^2 \\ \hat{\text{Var}}(\hat{V}) &= \sum_{h=1}^L \frac{N^2}{(nN_h)(nN_h-N)} \sum_{i=1}^{n_h} \left(\frac{y_{hi}}{p_{hi}} - \hat{V}_h \right)^2 \end{aligned}$$

The last equation is an unbiased estimator of $\text{Var}(V)$ and can be used for the estimation of the sampling error of the inventory.

Determination of Sample Size and size of PSU's.

From the usual confidence statement

$$P \left\{ \hat{V} - \left(t_{(\alpha; n-1)} \right) \left(\sqrt{\text{Var}(\hat{V})} \right) < \mu \leq \hat{V} + \left(t_{(\alpha; n-1)} \right) \left(\sqrt{\text{Var}(\hat{V})} \right) \right\} = 1 - \alpha ,$$

n may be obtained for a fixed precision level, (e.g. 5% of Y at 95% confidence level,) as follows:

Let $d = t \sqrt{\text{Var}(\hat{V})}$, i.e., half-width of conf. int., also called "allowable error"

$$d^2 = t^2 \text{Var}(\hat{V}).$$

Since

$$\text{Var}(V) = \frac{1}{n} \underbrace{\sum_i^N p_i \left(\frac{y_i}{p_i} - V_h \right)^2}_{S^2}$$

then

$$d^2 = \frac{t^2 S^2}{n}$$

and

$$n = \frac{t^2 S^2}{d^2} .$$

The value of S^2 is unknown in most applications and has to be estimated. Recalling that the population consists of N primary sampling units as a result of the partitioning of the forest on the ERTS image, the population variance S^2 is obtained by

$$S^2 = \frac{1}{N} \sum_{i=1}^N (y_i - \bar{y})^2$$

where y_i denotes the total volume of the i^{th} PSU, and \bar{y} their average.

The discriminant classification provides a means of estimating the value of y_i for each PSU, since each picture element had been assigned to a volume class. Thus, the weighted sum of these give the total volume of the PSU. More formally,

$$y_i = \sum_1^n \sum_k^m w.c$$

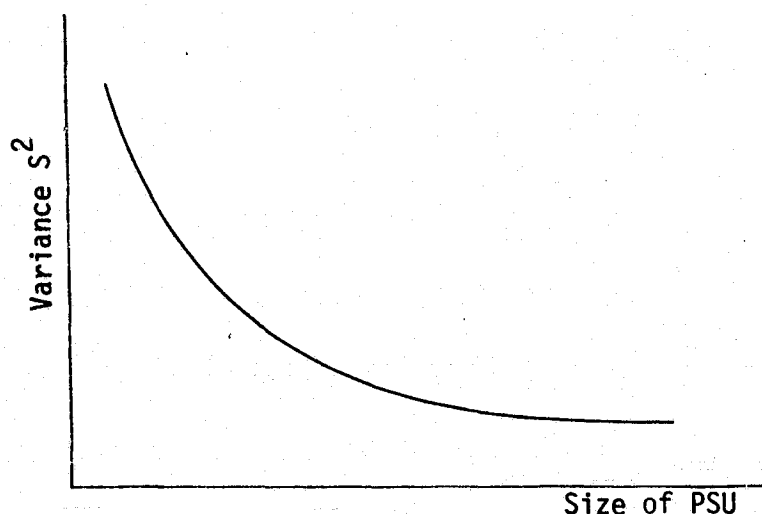
where $k=1, \dots, m$ is the index no. for rows of picture elements in PSU

$l=1, \dots, n$ is the index no. for columns of picture elements in PSU

w =volume weight for c

c =CALSCAN class assigned to $k1^{\text{th}}$ picture element

This approach also enables a study of the optimum size and shape of the PSU. Using the variance S^2 as a criterion and varying the size of the PSU, the following relationship may be obtained:



Similarly, by varying the sample unit width and length for a fixed size of PSU, and observing the S^2 , respectively, the optimal width/length ratio is found. The outcome of this particular study has to be qualified by practical considerations, e.g. those related to the procurement of the aerial photos of PSU's for subsequent sampling, the travel time within and between flight lines, and the ability to accurately locate the PSU's on maps and resource photography.

As a result, a rectangle of size 45 x 5 picture elements (404m x 2575m) has been selected as the optimum size of the PSU.

Using the coefficient of variation (CV) and a 95 percent level of confidence, the number of PSU's is found by

$$n = \frac{t^2 \cdot (CV)^2}{d^2}$$

Actually, for small sample sizes, the t-value changes significantly with n, and n has to be calculated by iterating with a new t-value.

Example,

(1) Assume $n = 13$, then $t_{(n-1)} = 2.18$ at 95% level.

Assume $CV = .18$

Let $d = t s_{\bar{x}} = .10$ (allowable error, i.e. half width of conf. int.)

Then

$$n = \frac{t^2(CV)^2}{d^2} = \frac{(2.18)^2 (0.18)^2}{(0.10)^2} = \frac{0.154}{0.01} = 15.4 \approx 16.$$

Second iteration: Assume $n = 15$, then $t_{(n-1)} = 2.13$ at 95% level

$$n = \frac{(2.13)^2 (0.18)^2}{0.01} = \frac{0.147}{0.01} = 14.7 \sim 15.$$

(2) Assume $n = 60$, then $t_{(n-1)} = 2.00$ at 95% level

Let $d = t \cdot s_{\bar{x}} = .05$, i.e. $s_{\bar{x}} = 2.5\%$

Then

$$n = \frac{(4) (0.0324)}{0.0025} = \frac{0.1296}{0.0025} = 51.8 \approx 52.$$

COMPARISON OF THE COST-EFFECTIVENESS OF AN ERTS BASED TIMBER
VOLUME INVENTORY AND A CONVENTIONAL TIMBER VOLUME INVENTORY

New operational systems for information gathering have come about with the advent of ERTS-1 and its space-age technologies. In order to evaluate their overall contribution to resource management, economic analysis has been employed. This form of analysis has proven valuable as one of several inputs to the decision making process.

In this section the results are reported for a study assessing the cost effectiveness of a multi-stage sampling technique for estimating timber volume utilizing ERTS in one stage. This was accomplished by comparing the estimated cost of the latter technique with the estimated costs of a more conventional multi-stage sampling method using an area of approximately 1 million acres. In the first part of this paper we examine these two approaches as comparative models; the assumptions of the cost-effectiveness analysis are then presented; the economic theory behind the benefit estimation follows; and finally, the benefit estimation is described.

Both the "ERTS" model and the "conventional" model had a three-stage sampling design in which a timber volume estimate was made at each stage; however, it was here that the similarity ended. In the first stage of the conventional model the initial stratification and sample set-up were done by human interpreters working on resource photography, whereas in the ERTS model the CALSCAN discriminant analysis of ERTS imagery accomplished these tasks.

In the second stage the primary sampling units of the conventional model were photographed at a scale of 1:4,000 as opposed to the larger scale of 1:1,000 used in photographing the PSU's in the ERTS model. In this stage it was assumed that the timber volume estimate produced by the ERTS model would be more accurate than the conventional model, due to the initial precision of the CALSCAN estimate and the work done on the larger scale photography.

From this assumption, we were able to allocate to the ERTS model a smaller ground sample size in the final stage. Specifically, two .4 acre ground plots were considered necessary in each PSU for the ERTS model and seven in each PSU for the conventional model.

Our conventional model resembled a sampling method recently used by the U.S. Forest Service in the Stanislaus National Forest. We did, of course, modify this sampling method to fit our computer system. In estimating the costs for the conventional model, we were guided by some relevant cost data derived from the actual Stanislaus inventory as well as from our own research

in the costs of the various photo interpretation techniques. On the other hand, the costs of the ERTS model were developed from projections based on its application in the Quincy Ranger District of the Plumas National Forest.

7.31 Assumptions

For the purposes of the study, a number of assumptions were made as follows: (1) only the operating costs, and not the total costs were considered for each model; (2) the value of information from both methods was assumed to be the same, i.e. the quality, quantity and timeliness of the information of both systems had the same impact on tastes or preference; (3) costs were based on obtaining a 95% level of confidence; (4) aerial photography, which was used in both models, was considered to be free of charge since it is readily available in the U.S.; (5) the cost of the ERTS tapes for the study area was the only cost component of the ERTS system considered here; (6) the labor cost for both studies was based on University of California rates; and (7) all computer costs were based on G.S.A. contract rates.

7.32 Economic Theory

To derive the benefit estimation for the ERTS model, cost-effectiveness analysis can be used since the assumption has been made that the two models are equal in respect to value of information. From an economic standpoint, then, we may assess this value of information on cost considerations only. The question we are concerned with resolving is simply: which model provides the information with the least expense, or more broadly, which model reflects the optimum level of production? Inherent in this question is the value judgement that society benefits from a constant or increased amount of goods and services acquired with less inputs, i.e. lower costs.

In cost-effectiveness analysis we are interested in generating a curve which represents the maximum capability of the system for each level of expenditure. That is, an increase in the budget will always be matched by an increase in capability, and likewise a decrease in the budget will have the opposite effect. What we arrive at finally is a cost curve, or so called "production frontier", composed of the set of cost-efficient points as seen in the curve F_1F_1 in Figure 1.

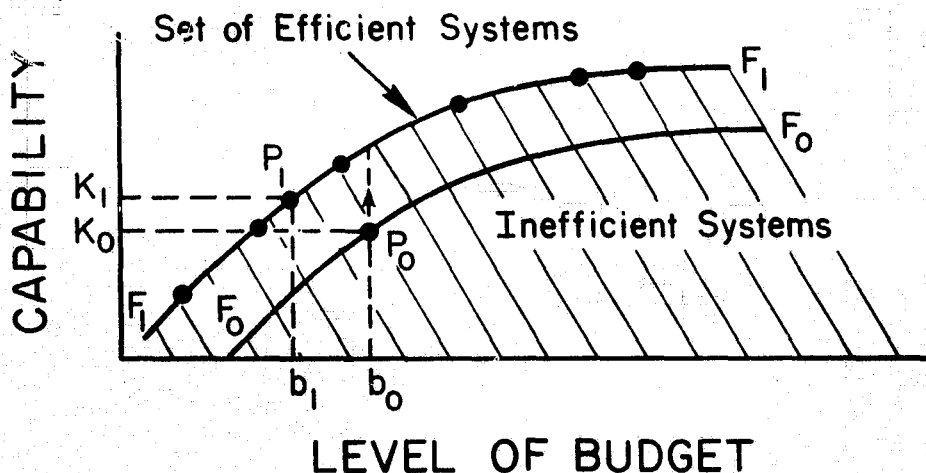


Figure 1. The Cost Curve F_1F_1 reflects the increase in efficiencies associated with the introduction of new technologies.

We want to examine closely the impact which the new technology (i.e., the ERTS model) has on the production frontier. Theoretically, the production frontier will shift outward to the left with the introduction of new technologies. As shown by the graph, when this occurs a previously efficient system at point P₀ on the curve F₀F₀ becomes inefficient because the same capability now can be obtained at a lower budget expenditure. The decision maker must approach this new condition in either of two ways: (1) as an equal capability efficiency problem or (2) as an equal budget efficiency problem. In the first, the decision is whether the cost benefits (i.e. savings) associated with the same level of capability are worth the investment in new hardware of the alternate system. In the second, on the other hand, the decision is whether the increased capability at the same level of budget is worth the investment. (Willow Run Laboratories, 1972, pp. 90-96.)

7.33 Results and Conclusions

To apply cost-effectiveness analysis to the ERTS model and the comparative conventional model it was necessary to determine the production frontiers of each model for a 95% confidence level (t) and the associated costs. This was accomplished in both models by calculating various sample sizes (PSU's) with each sample size corresponding to a specific allowable error. In this regard, it was determined that the largest percentage of variable costs are directly related to the size of the sample area.

In the conventional model the number of primary sampling units over a range of allowable errors was found by using a statistical exercise outlined by Cochran (1953) on the inventory figures found in the Timber Management Plan of the Stanislaus National Forest. Using this procedure an estimate of the population coefficient of variation (CV) was obtained (59%). The figures obtained for the conventional model were:

AE	PSU's	Ground Plots	Total Costs
20%	6	42	\$31,427
15%	9	63	34,688
10%	18	126	44,600
5%	62	434	92,941

A complete break-down of the costs may be found in Table 2.

In order to derive the production frontier for the ERTS model the following equation for sample size determination (n) was used (see pp. 11-12 for a more complete treatment of the equation):

$$n = \frac{t^2 \cdot (CV^2)}{d^2}$$

CV is the coefficient of variation for the ERTS model estimator, a measure of population and sampling variability as well as measurement errors. The estimator in this case was based on probability proportional to estimated size.

The magnitude of CV depends largely on the quality of auxiliary information which, if good, would reduce the variation associated with the estimator. The auxiliary information in this case would be the timber volume estimate generated by CALSCAN.

Since we had not inventoried the Stanislaus National Forest we had to arrive at an estimate of the CV by utilizing our experience of inventorying the Quincy Ranger District of the Plumas National Forest. In this inventory the CV obtained was 22% whereas the Forest Service estimate of the population variability for this area was 80%. From this finding we made the assumption that for the area of northeastern California we could expect to reduce the population variability arrived at in a conventional inventory by approximately 75%. Consequently, we determined the CV for the ERTS model to be 15% for the Stanislaus (25% of 60%). The figures arrived at were:

AE	PSU	Ground Plots	Total Cost
20%	5	10	\$11,526
15%	7	14	12,304
10%	12	24	14,494
5%	37	74	26,074

A complete break-down of costs may be found in Table 3.

From this information the following production frontier curves were generated as seen in Figure 2:

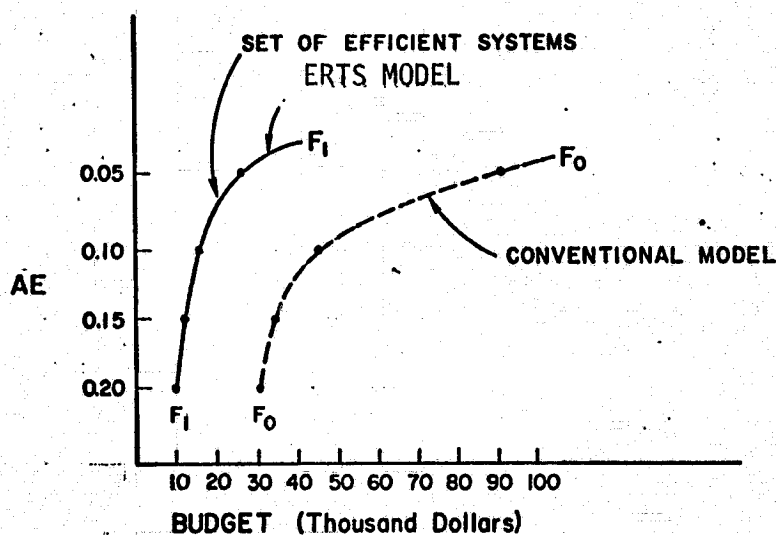


Figure 2. Curve F_1F_1 represents the production frontier of the ERTS multistage sampling model and shows the latter to be a more efficient system than the conventional model, represented by the curve F_0F_0 .

It is clear that the ERTS model was a more efficient system of inventorying and therefore should replace the conventional design. As shown in Table 1, the estimated cost-effectiveness ratio increased as the allowable error diminished. At a 10% AE the benefit was 3.08:1 and at a 5% AE it was 3.56:1. This gain in efficiencies was largely the result of the following two main cost differences: (1) first stage procedures and (2) map generation. As to the first, in the conventional model the initial stratification of the area was done mainly by human interpreters using resource photography whereas in the ERTS model, operating on ERTS data, CALSCAN provided a point by point classification of the area at a lower cost and with greater precision. With this higher level of precision, coupled with the work done on large scale stereo triplets, a less costly sampling scheme was obtainable.

As to the second difference, that of map generation, this study found that a WRIS black-and-white boundary map of a township at a scale of 4 inches to a mile could be processed by computer for approximately \$200. Using the ERTS model system, on the other hand, a color-coded township map of the same scale could be processed for roughly \$50.

Although the cost efficiency approach to benefit analysis provides a good estimator, it does not consider the tastes or the preference of society. The analysis therefore, does have some weakness when one considers that society sometimes places a greater value on inefficient systems rather than efficient ones.

Benefit-cost analysis, if properly used, can serve as an evaluation tool; its conceptual limitations must, however, be taken into account whenever decisions about procedure and policy must be made. Undue reliance on a "technological quick-fix", especially when quantitative manipulation is possible, can encourage short-run measures that may ultimately ignore or violate long-term consequences. No easy approaches to the larger context are offered here, but as possible costs and returns are brought to the surface for comparison and critical appraisal, it can be expected that the decision-making process will be improved so as to improve the management of forest resources and, ultimately, even to appeal to the public's environmental interests.

TABLE 1: Cost Comparison Summary at a 95% Confidence Level

ERTS Model

Conventional Model

Task	20% AE 5 PSU's 10 Ground Plots	15% AE 7 PSU'S 14 Ground Plots	10% AE 12 PSU's 24 Ground Plots	5% AE 37 PSU's 74 Ground Plots	20% AE 6 PSU's 42 Ground Plots	15% AE 9 PSU's 63 Ground Plots	10% AE 18 PSU's 126 Ground Plots	5% AE 62 PSU's 434 Ground Plots
I Stratify/ Classify	\$ 2,267	\$ 2,313	\$ 2,428	\$ 3,003	\$ 5,145	\$ 5,145	\$ 5,145	\$ 5,145
II Photo Acquisition/ Interpretation	\$ 437	\$ 583	\$ 946	\$ 2,923	\$ 396	\$ 557	\$ 1,114	\$ 3,585
III Ground Data Collection	\$ 976	\$ 1,255	\$ 2,091	\$ 6,552	\$ 3,764	\$ 5,576	\$11,013	\$37,777
IV Data Summary & Map Generation	\$ 3,290	\$ 3,290	\$ 3,290	\$ 3,290	\$ 9,700	\$ 9,700	\$ 9,700	\$ 9,700
Sub-Total	\$ 6,970	\$ 7,441	\$ 8,755	\$15,768	\$19,005	\$20,978	\$26,972	\$56,207
Administrative Costs (27%)	\$ 1,882	\$ 2,009	\$ 2,364	\$ 4,258	\$ 5,132	\$ 5,664	\$ 7,283	\$15,176
Overhead (30.2%)	\$ 2,674	\$ 2,854	\$ 3,358	\$ 6,048	\$ 7,290	\$ 8,046	\$10,345	\$21,558
TOTAL	\$11,526	\$12,304	\$14,478	\$26,074	\$31,427	\$34,688	\$44,600	\$92,941
Cost-effective Ratio	2.73:1	2.82:1	3.08:1	3.56:1				

TABLE 2: Conventional Model Cost Breakdown
at a 95% Confidence Level

	.20 AE 6 PSU's 42 Ground Plots	.15 AE 9 PSU's 63 Ground Plots	.10 AE 18 PSU's 126 Ground Plots	.05 AE 62 PSU's 434 Ground Plots
I. PRE Photo/Ground ¹				
A. Resource Photo Procurement	NO COST	NO COST	NO COST	NO COST
B. Labor				
1. Delineation of Boundaries				
A \$7.00/hr	714.00	714.00	714.00	714.00
2. Plotting effective areas	630.00	630.00	630.00	630.00
3. Interpreter training	56.00	56.00	56.00	56.00
4. Type delineation & classification	3,633.00	3,633.00	3,633.00	3,633.00
5. Sample set-up	112.00	112.00	112.00	112.00
Labor sub-total	<u>5,145.00</u>	<u>5,145.00</u>	<u>5,145.00</u>	<u>5,145.00</u>
II. Photo Acquisition & Interpretation ²				
A. Aircraft - \$28/hr.	42.00	63.00	126.00	434.00
B. Pilot & Crew - \$15/hr.	23.00	34.00	68.00	233.00
C. Film Processing \$32/flight line	78.00	117.00	234.00	806.00
D. Annotation of film \$10/ " "	60.00	90.00	180.00	620.00
E. Interpretation of photos \$20/ " "	120.00	180.00	360.00	1,240.00
F. Selection of Ground Plots	20.00	20.00	40.00	40.00
G. Travel to & from Stanislaus	53.00	53.00	106.00	212.00
Photo acquisition sub-total	<u>396.00</u>	<u>557.00</u>	<u>1,114.00</u>	<u>3,585.00</u>
III. Ground Data Collection ³				
A. Travel - vehicle @\$9.40/day	254.00	376.00	743.00	2,547.00
B. Crew - 2 men @\$40/day each	2,160.00	3,200.00	6,320.00	21,680.00
C. Per diem days X 2 X \$25/day	<u>1,350.00</u>	<u>2,000.00</u>	<u>3,950.00</u>	<u>13,550.00</u>
Ground data sub-total	<u>3,764.00</u>	<u>5,576.00</u>	<u>11,013.00</u>	<u>37,777.00</u>
IV. Data Summary & Map Generation				
A. Computer analysis of Gnd & Photo data @\$40/day	160.00	160.00	160.00	160.00
B. Generation of summary statistics @\$40/day	40.00	40.00	40.00	40.00
C. Report preparation & reproduction	650.00	650.00	650.00	650.00
D. Computer-time	250.00	250.00	250.00	250.00
E. Map Generation	<u>8,600.00</u>	<u>8,600.00</u>	<u>8,600.00</u>	<u>8,600.00</u>
Data summary sub-total	<u>9,700.00</u>	<u>9,700.00</u>	<u>9,700.00</u>	<u>9,700.00</u>
Sub-Total	<u>19,005.00</u>	<u>20,978.00</u>	<u>26,972.00</u>	<u>56,207.00</u>
Administrative (27%)	<u>5,132.00</u>	<u>5,664.00</u>	<u>7,283.00</u>	<u>15,176.00</u>
OVERHEAD				
(30.2%-Subtotal & Admin.)	7,290.00	8,046.00	10,345.00	21,558.00
TOTAL	<u>31,427.00</u>	<u>34,688.00</u>	<u>44,600.00</u>	<u>92,941.00</u>

¹Cost estimates were based on the photo interpretation costs reported in "Analysis of Remote Sensing Data for Evaluating Vegetation Resources" by Forestry Remote Sensing Laboratory, University of California, Berkeley, 30 September 1972.

²The aircraft costs were based on flying 4 flight lines an hour and flying a maximum of 16 flight lines a day.

³Ground data collection costs were based on completing 1.6 ground plots per day

TABLE 3: ERTS Model Cost Breakdown
at a 95% Confidence Level

	.20 AE 5 PSU's 10 Ground	.15 AE 7 PSU's 14 Ground	.10 AE 12 PSU's 24 Ground	.05 AE 37 PSU's 74 Ground
PRE Photo/Ground				
A. Tape Acquisition	\$ 360.00	\$ 360.00	\$360.00	\$ 360.00
B. Tape Reformatting				
1. Tape	7.75	7.75	7.75	7.75
2. Computer time 1/4 hr @\$40/hr	10.00	10.00	10.00	10.00
3. Operator	2.25	2.25	2.25	2.25
C. Intensive Area Extraction				
1. Computer 1/2 hr @40/hr	20.00	20.00	20.00	20.00
2. Operator 1 hr @ 5/hr	5.00	5.00	5.00	5.00
D. Delineation and Extraction of Administrative Unit				
1. Photo Reduction	15.75	15.75	15.75	15.75
2. Digitizer with operator 2 hr @16.50	33.00	33.00	33.00	33.00
3. Computer mask generation				
a. computer	12.50	12.50	12.50	12.50
b. operator 3 hr @5	15.00	15.00	15.00	15.00
E. Training of Classifier (60 classes)				
1. Computer display terminal 8 hr @40/hr	320.00	320.00	320.00	320.00
2. Image Analysts 40 hr @7.00/hr	280.00	280.00	280.00	280.00
3. Statistical analysis (LBL) 10 A 12	120.00	120.00	120.00	120.00
4. Selection of channels & classes 16 hrs @5	80.00	80.00	80.00	80.00
F. Discriminant analysis run				
computer	630.00	630.00	630.00	630.00
analyst	80.00	80.00	80.00	80.00
G. Generation and selection of PSU				
computer	120.75	120.75	120.75	120.75
analyst	40.00	40.00	40.00	40.00
H. Location of PSU				
computer	52.00	73.00	125.00	383.00
analyst	63.00	88.00	151.00	468.00
Subtotal	\$2,267.00	\$2,313.00	\$2,428.00	\$3,003.00

TABLE 3: Continued

	.20 AE 5 PSU's 10 Gnd Plots	.15 AE 7 PSU's 14 Gnd Plots	.10 AE 12 PSU's 24 Gnd Plots	.05 AE 37 PSU's 74 Gnd Plots
I. Photo Acquisition and Interpretation ⁴				
A. Aircraft \$28/hr	35.00	49.00	84.00	280.00
B. Pilot and Crew \$15/hr	18.75	27.00	45.00	150.00
C. Film & processing \$32/flt. ln.	160.00	224.00	384.00	1,184.00
D. Annotation of film \$10/" "	50.00	70.00	120.00	370.00
E. Interpretation of photos \$20/" "	100.00	140.00	240.00	740.00
F. Selection of Ground plots	20.00	20.00	20.00	40.00
G. Travel to & from Stanislaus	53.00	53.00	53.00	159.00
Subtotal	436.75	583.00	946.00	2,923.00
II. Ground data collection ⁵				
A. Travel - vehicle @\$9.40/day	66.00	85.00	141.00	442.00
B. Crew - 2 men @\$40/day each	560.00	720.00	1,200.00	3,760.00
C. Per diem X 2 X \$25/day	350.00	450.00	750.00	2,350.00
Subtotal	976.00	1,255.00	2,091.00	6,552.00
V. Data Summary and Map Generation				
A. Computer analysis of Ground and Photo data 4 days @40/day	160.00	160.00	160.00	160.00
B. Combining ERTS and Ground data 1 day @40/day	40.00	40.00	40.00	40.00
C. Generation of Summary Statistics 1 day @40/day	40.00	40.00	40.00	40.00
D. Generation of Maps	2,150.00	2,150.00	2,150.00	2,150.00
E. Report preparation and reproduction	650.00	650.00	650.00	650.00
F. Computer time	250.00	250.00	250.00	250.00
Data Summary Subtotal	3,290.00	3,290.00	3,290.00	3,290.00
Subtotal	6,970.00	7,441.00	8,755.00	15,768.00
Administrative (27%)	1,882.00	2,009.00	2,364.00	4,258.00
Overhead (30.2%)	2,674.00	2,854.00	3,358.00	6,048.00
TOTAL	11,526.00	12,304.00	14,476.00	26,074.00

⁴ The aircraft costs were based on flying 4 flight lines an hour and flying a maximum of 16 flight lines a day

⁵ Ground data collection costs were based on completing 1.6 ground plots per day

An interdisciplinary inter-agency renewable resource survey, inventory and mapping system based on computer analyzed ERTS multispectral scanner data appears to be a cost-effective alternative to the independent information gathering procedures now being used. This statement is supported by the increasing evidence that through proper human-computer analysis of ERTS multispectral data much of the information necessary for resource allocation, management, inventory assessment, and mapping can be obtained very cost-effectively. By complementing this ERTS derived data base, through the use of minimal analysis of small scale photography, large-scale photography and ground data, one can meet or exceed the current information gathering standards imposed on the various agencies involved in the management of our renewable natural resources.

The primary characteristics of this cost-effective integrated information gathering system include:

- a. Broad uniform data base
- b. Suitable spatial resolution
- c. Suitable spectral resolution
- d. Direct computer compatibility
- e. Periodic coverage
- f. Systematic coverage
- g. Geometric fidelity

The spatial and spectral resolution characteristics of the digital data appear to be nearly optimum for computer mapping of surface vegetation characteristics at the plant community level over a vast majority of the U.S. wildland areas. The picture element-by-picture element processing of this digital data provides acre-by-acre discrimination of surface characteristics. This provides information at a higher order of resolution and consistency than can be cost-effectively obtained by photo interpretation of conventional resource photography having a scale of 1:15,840 and 1-3 foot ground resolution when using 10-40 acre mapping minimums.

The systematic coverage from ERTS provides a uniform computer-compatible data base over large areas allowing the surface characteristics' analysis to be done by environmentally similar units rather than by the arbitrary administrative, political or management units currently in use. Because of this consistency over broad environmental units and the precision and accuracy of the computer analysis of the ERTS data, samples can be allocated more efficiently. This increased efficiency significantly reduces the number of samples required, further reducing the cost of the total information gathering system.

The geometric fidelity, spatial resolution and computer compatibility of the analysis and sampling combine to make for simple and inexpensive overlaying of administrative management boundaries, ownership boundaries and political boundaries. With these boundaries overlain, information can be extracted from the environmentally oriented ERTS data base in the combinations required to meet administrative, management, ownership and policy information needs.

The final yet extremely important component in the ERTS system is its ability to provide periodic coverage with essentially identical spectral and geometric characteristics. This makes the overlaying of data, acquired at desired dates, accurate and relatively inexpensive. This overlay of data allows the periodic updating of the resource information base through the identification and mapping of changes in the surface characteristics. It has been shown that ERTS resolution will allow the detection and mapping of timber harvesting operations, fire damage, wind damage and land-use change. This information on change can then be used to allocate samples to assess the change rather than completely reworking the information base, as is currently done.

The following is a brief description of the steps that would be used for inventory, assessment and mapping of the renewable resources using ERTS multispectral scanner data as the base for this environmentally oriented information collection system.

- 1) To allow the use of optimum discriminant analysis procedures and photo-ground sample allocation, environmentally similar sub-areas would be delineated over very broad areas. For example, in the Sierras of Northern California the area would be divided into four basic environmental strata: a) eastside pine, b) high elevation true fir, c) mixed conifer and d) oak woodland.

- 2) The next step in the procedure would be the general picture element-by-picture element discriminant analysis of the ERTS digital data within the delineated environmental areas. This analysis would classify the area into the following land use categories as defined by Anderson in Geological Survey Circular 671: a) urban and built-up land, b) agricultural land, c) range land, d) forest land, e) water, f) non-forest wet land, g) barren land, h) tundra and i) permanent snow and ice field.

- 3) Within each of the broad classes, a detailed discriminant analysis would be run to further sub-divide classes of high interest. For example, within the forest lands the discriminant analysis would be designed to separate the forest lands by type and condition class. In the range land areas, the analysis would be directed towards the separation of plant communities relating to productivity, potential productivity, and intensive management requirements.

4) At this point the results of the environmental strata delineation, surface category definition, and the detailed discriminant analysis would be used to allocate samples to areas where more precise and accurate estimates are required. For example, in the forest surface category within one or more general environmental types, samples could be allocated for timber volume estimation, growth estimation and timber type determination.

5) The scale and type of photography appropriate to the resource being surveyed will then be flown and interpreted. In the rangeland areas, the interpretation would be for species composition, soil surface characteristics, and vegetation condition. In the forested areas the interpretation would include forest type, condition class, volume, site characteristics and recreation potential.

6) A small number of selected photo plots would then be visited on the ground to obtain the final and most precise estimates of the parameters of interest.

7) A smaller number of selected photo plots would be established as permanent ground plots to be visited in future inventories. Such remeasurement plots would allow inferences to be made concerning plots not revisited, while at the same time allowing new plots to be measured. In this manner, a more complete sample of the diversity inherent in the environment could be made, thus allowing even narrower confidence bands to be placed around estimates of environmental quantities.

8) All photo plots, ground plots and permanent plots would be precisely located in a ground coordinate system that would be tied through control points to the ERTS coordinate system used in the original discriminant analysis procedure. Using this precise plot location information the photo plots would be matched to the ERTS discriminant analysis results. The results of the classification of the located picture elements and the photo interpretation of the large scale photos and ground data would then be established. The establishment of this relationship between the photo-ground results and the ERTS results and the confidence in that relationship would be used in the next step in the inventory to summarize data by management unit, administrative area, and political boundaries.

9) The administrative, management, ownership, and political boundaries would then be digitized and overlain on the results of the discriminant analysis. From the relationship established between the photo ground analysis and the ERTS discriminant analysis and this ability to extract the discriminant analysis results by arbitrary units of interest, summary and mapping of environmental information could be performed for the various administrative and interest groups as needed.

10) To obtain necessary statistics for planning, policy and administration at the regional, state and national levels, the results from various environmental units would be added together to provide information for the higher levels of management, planning and policy making within the various agencies and branches of government.

11) To update the information base, ERTS data would be obtained periodically and overlaid on the original ERTS data base. Using the training areas from the previous date and a few additional training areas to define major changes, a discriminant analysis would be done to detect and map changes in the environment such as logging, urban development, hydroelectric development, fire and wind-throw. After a significant level of change has been identified, mapped, and assessed using the ERTS data, a supplemental quantity of conventional and large scale photography could be acquired to update the sampling base. Based on the information obtained from these human analyzed photos a very small number of plots would be selected for measurement on the ground to update the relationship between the ERTS data and the photo-ground data. It is important to note that the sample allocation for photo plots and ground work would be mainly in the areas where changes have occurred and with a few permanent plots maintained to tie the inventory on the second date to the inventory on the first.

12) To allow the efficient utilization of this data, the discriminant analysis results and statistical summaries would be made compatible with the existing resource allocation models (RAM) and the natural resource information systems (NRIS).

13) The unique characteristic of the ERTS discriminant analysis providing an in place mapping of the surface characteristics makes it ideal as an input to a dynamic resource allocation and model simulator. This futuristic approach to resource allocation, resource management and yield prediction would include a number of auxiliary inputs such as meteorological satellite data, topographic information and ground station information.

There are several data gathering statistical analysis techniques and data processing techniques that must be put together to provide an operational system. The current operational status of these techniques is shown in Table IV. The current status of the individual discipline oriented ERTS based estimation and mapping is shown in Table V.

Table IV

Operational status of data collection
and information processing technology

	Operational	Testing	Implementation	Research and Devel.	Planning	Proposed
Ground Data Collection	X					
Delineation and Processing of Homologues	X ¹					
Discriminant Analysis for Land-Use	X					
Discriminant Analysis for Vegetation Type and Condition Class	X ¹					
Sample Design and Plot Allocation	X ¹					
Large Scale Photo Acquisition and Interpretation	X ¹					
Location of Photo Ground Plots in Discriminant Analysis Results		X				
Correlation of Photo Interpreter Ground Evaluation with ERTS Classes for Evaluation of Site, Type and Condition for:						
A. Timber		X				
B. Range			X			
C. Land-Use		X				
D. Protection				X ⁴		
Overlay of Administrative, Ownership and Management Boundaries	X ²					
Adding of Local Environmentally Based Surveys to Obtain Regional Estimates				X		
Subdivision of Environmental Areas to Provide Estimates by Management Unit, and Administrative Unit, and Agency Jurisdiction		X				
Provide Data to Resource Allocation Model (RAM)						X
Provide Data to Natural Resource Information System (NRIS)					X ³	
Develop and Provide Data to Dynamic Resource Allocation Model and Simulator (DRAMS)						X

1. The procedures are operational but are being made more cost-effective through continuing research.
2. The process is operational but accuracy and efficiency need to be improved.
3. Bureau of Land Management study.
4. USFS study for wildland fuel mapping.

Table V

Current status of ERTS based
estimation and mapping capabilities

	OPERATIONAL	TESTING	IMPLEMENTATION	DEVELOPMENT	RESEARCH	PROPOSED
VOLUME ESTIMATION AND MAPPING	X					
GROWTH ESTIMATION AND MAPPING		X				
CONDITION CLASS MAPPING AND AREA ESTIMATION		X				
LAND-USE MAPPING AND AREA ESTIMATION	X					
SITE DETERMINATION AND MAPPING					X	
CHANGE DETECTION AND MAPPING			X			
WATERSHED PARAMETER MAPPING		X				
FIRE HAZARD MAPPING		X				
RANGELAND VEGETATION MAPPING	X					
HIGH INTEREST SITE IDENTIFICATION		X				
RANGELAND POTENTIAL PRODUCTIVITY MAPPING					X	
RANGELAND ANNUAL PRODUCTIVITY ESTIMATION						X
WILDLAND FUEL CONDITION DETERMINATION					X	

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CHAPTER 8

COST-EFFECTIVENESS COMPARISON OF EXISTING AND LANDSAT-BASED TOTAL TIMBER RESOURCES INVENTORY SYSTEMS

Preliminary Report

A Special Presentation to Office of
Applications, NASA Hdqts. Funded under
NASA Grant No. NGL05-003-404

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CHAPTER 8

TABLE OF CONTENTS

8.000	Introduction	8-1
8.100	Assumptions	8-1
8.200	Economic Theory	8-2
8.300	Comparison of Systems	8-3
8.310	Comparative Sampling Designs	8-4
8.311	Forest Service Sampling System	8-4
8.312	LANDSAT-based Sampling System	8-5
8.320	Comparative Costs	8-7
8.21	Forest Service Sampling System	8-7
8.400	Results and Conclusions	8-13
Appendix I:	Optimum Sample Allocation in Double Sampling for Regression	8-16
Appendix II:	Detailed Costs of LANDSAT-Based Timber Resources Inventory System, Plumas National Forest, 1974	8-20

CHAPTER 8

COST-EFFECTIVENESS COMPARISON OF EXISTING- BASED TOTAL TIMBER RESOURCES INVENTORY SYSTEMS

8.000 INTRODUCTION

Economic analysis is an integral part of the process by which new technologies find practical applications. In its brief history, LANDSAT-1 has demonstrated great promise for beneficially altering the time, cost, and capability relationships existing in many resource management areas. LANDSAT offers some of the most direct cost savings in resource inventory work, where budgets are particularly sensitive to reductions in the costs of gathering information.

This study examines the utility of LANDSAT imagery in a total timber resource inventory application. In California's million-acre Plumas National Forest, a LANDSAT-based sampling technique is compared with inventory methods similar to those currently employed by the U. S. Forest Service. The two sampling systems are evaluated as to their relative cost-effectiveness. Comparison is possible because both systems produce the same sort of output: information about timber growth and yield potential for a variety of forest vegetation types and stand condition classes. Such information is indispensable for the timber management planning process.

The study's major elements are summarized below in four sections. First, the general assumptions behind the analysis are outlined. This is followed by a brief description of the economic theory of cost-effectiveness analysis. A third section compares the two systems both in terms of their sampling designs and their costs. Finally, comparative results and conclusions follow.

8.100 ASSUMPTIONS

A number of assumptions were made to facilitate the analysis. Paralleling cost-effectiveness theory, it was assumed that both the existing and LANDSAT-based systems operate on their respective production frontiers. With respect to sampling design, the LANDSAT-based system was assumed capable of achieving the same gains in stratification as the existing system. Assumptions regarding costs were as follows: only operating costs were considered for each system; aerial photography was considered free of charge in the existing inventory system; the cost of LANDSAT tapes was the only cost allocated from the LANDSAT program; and data summary costs and administration and overhead rates for both systems were assumed to be equal.

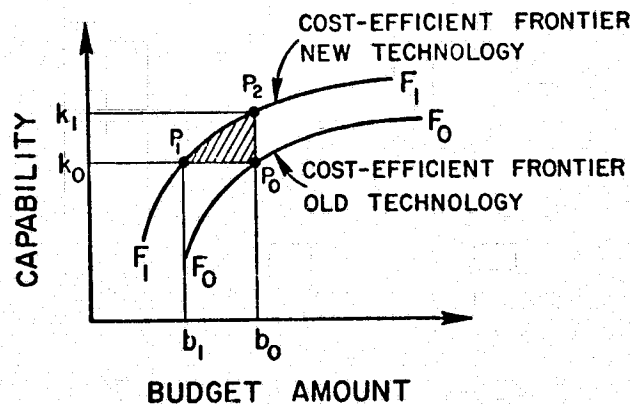
8.200 ECONOMIC THEORY

Cost-effectiveness analysis helps a decision-maker answer questions about how to achieve a given set of objectives at the least cost, or how to obtain the most effectiveness from a given set of resources. Economic benefits are described in terms of cost savings. One variety of cost-effectiveness analysis is the "system comparison study." Here, the cost and capability relationships of two or more systems with the same output are examined side-by-side. It is commonly presumed that the competing systems have already been optimized as to their internal configurations. This type of analysis enables a decision-maker to assess the marginal improvement promised by alternative systems.

A comparative cost-effectiveness analysis was used in this study since the two systems involved provided approximately equivalent information. From an economic standpoint, the question to be resolved is simply: which system provides the information with the least expense, or more broadly, which system reflects the optimum level of production? Inherent in this question is the value judgment that society benefits from a constant or increased amount of goods and services acquired with less inputs, i.e. lower costs.

The theory behind cost-effectiveness analysis may be expressed graphically. Figure 1 illustrates the effect of technological progress on the cost-capability "frontier" of an existing production system.

FIGURE 8.1: EFFECT OF A TECHNOLOGICAL ADVANCE ON A COST-CAPABILITY PRODUCTION FRONTIER



The frontier F_0F_0 shows the maximum capability that can be expected from the present system at a given level of budget. A system producing on the frontier is defined as "cost-effective" because a decrease in cost is not possible without a decrease in capability. A technological advance would beneficially alter this relationship: the cost-efficient frontier would be pushed out to some new set of points as on F_1F_1 . A point P_0 on the old frontier F_0F_0 would now represent an inefficient pattern of production. A set of points in the shaded area of Figure 1 would represent an improved return, with cost-efficient points now lying on F_1F_1 between P_1 and P_2 . The effect of technological progress thus ranges between either equivalent capability at a lower budget (P_1) or greater capability within the same budgetary constraints (P_2).

A decision maker will want to examine closely the impact which a new technology has on the production frontier. He may approach this objective in either of two ways: (1) as an equal capability efficiency problem, or (2) as an equal budget efficiency problem. In the first, the decision is whether the cost benefits (i.e. savings) associated with the same level of capability are worth the investment in new hardware of the alternative system. In the second, the decision is whether the increased capability at the same level of budget is worth the investment.

8.300 COMPARISON OF SYSTEMS

Real world complications tend to force applied cost analyses into a compromise with theoretical perfection. Most of the application difficulties encountered in this study concerned the development of a suitable basis of comparison for the two timber resource inventory systems. Ideally, an applied analysis would directly compare inventory systems while holding constant the time and location of a representative and comprehensive inventory. In reality, modifications were necessary to fit existing cost and performance data into a comparable framework. The main application problems encountered in this study may be highlighted as follows:

- o The LANDSAT-aided inventory was performed on the Plumas National Forest in 1974. Although the analysis assumes a cost-efficient production system, the "first run" nature of the Plumas/1974 inventory leaves room for improved cost-performance relationships.
- o The last U.S. Forest Service (USFS) inventory on the Plumas National Forest was performed in 1969.
- o Forest-Service inventory techniques have been steadily evolving since 1969. Based on current Forest Service inventories in other forests, it is likely that a hypothetical Plumas/USFS - 1974 inventory would have a different cost-performance relationship than the actual Plumas/USFS - 1969 inventory.

The next two subsections on comparative sampling design and costs describe how the above considerations were addressed operationally.

8.310 COMPARATIVE SAMPLING DESIGNS

8.311 Forest Service Sampling System

8.311.1 Output

The system is designed to provide information input to the timber management planning process for the USFS lands and to provide information for the National Forest Survey on both public and private lands. Primary emphasis is on providing information in a form which may be easily linked with the Forest Service Resource Allocation Model (RAM). Estimates of growth and yield are required by various categories of management opportunities, or activity classes in the RAM terminology. A significant part of the definition of activity classes is the physical state of the resource as defined by major forest vegetation types and stand condition classes. The vegetation type and condition class provide for a logical stratification of the forest, and within each stratum estimates of yield and growth are the major parameters for which estimates are desired.

8.311.2 General system features

Stratification of the forest into forest type and stand condition categories is a major feature of the design. Operationally this stratification is obtained by producing a forest type map using recent aerial photography and, if available, previous type maps as source data. The completed type maps are then digitized and entered into the WRIS (Wildland Resource Inventory System) mapping system and a summary of acreages by strata is produced.

Based on the acreages and strata weights produced by the WRIS system, a stratified two-stage sample is undertaken to obtain sample data for the parameters of interest. Allocation of samples is made proportional to acreage in each stratum; typically there are 15 to 20 strata. The stage one sample consists of a number of townships or primary sampling units (PSU's) selected with a probability proportional to the number of acres in the stratum of interest. The stage two sample, conducted within each selected PSU, consists of selecting two plot locations at random within the township and the stratum of interest. At each plot location, a cluster of 5-point samples provides the opportunity for measurement of the variables associated with the parameters of interest. Individual trees are selected for measurements using "point sampling" techniques (Husch, et al., 1974). Tree volumes are obtained using Forest Service volume tables.

8.311.3 Sample size and allocation

Based on Forest Service experience with several other California forests,

it is probable that a sample size of no more than 150 ground plots (5-point clusters) or 75 PSU's would be taken on the Plumas National Forest with the precision requirements of ± 5 percent allowable error at the 1 standard error level of confidence (0.68 probability). Stratification of the population would produce 15 to 20 strata.

8.312 LANDSAT-based Sampling System

8.312.1 Output

The LANDSAT based system is designed to produce essentially the same information as the Forest Service system. Specific measurement techniques vary somewhat from the USFS system. However, the basic growth and yield output by major vegetation types and condition classes remains the same.

8.312.2 General system features

Again, stratification is an important first step in the process. It is accomplished by a pointwise discriminant analysis using the CALSCAN package of programs to analyze raw LANDSAT MSS data. At the present time, stratification has been limited to four classes of major forest type. However, with further work it is expected that a more detailed stratification will evolve comparable to that of the USFS system. This level of detail for estimation purposes is currently achieved by summarizing estimates by domains of interest within the population (Cochran, 1963). Based on the results of the stratification, a multistage sample is undertaken as follows.

The stage one PSU's are defined as 45 x 5 pixel units and are selected with varying probabilities in the same manner as the USFS stage one sample. The stage two sample consists of 10 photo plots selected within each of the selected PSU's. The photo plots are located on a flight line through the center of the PSU; exact location is governed by the center points of large scale photographic images (1:1,000 \pm). Observations are made on each photo plot including classification into a detailed type and condition class, and determination of species, height and crown diameter for each tree located within a 0.4-acre circular plot.

Stage three provides a double sampling link with the ground by selecting a restricted random sample of photo plots for further detailed measurement on the ground. The restriction is that samples are obtained in each type and condition class proportionally to the number of photo plots in each class. Ground measurement of the same physical area interpreted by a photo interpreter included detailed classification of the type, condition, terrain, and vegetation, as well as species, diameter, increment, and tree class for each tree. Stage four provides a double sampling link between basic tree measurements and more precise measures of volume, surface area, and height obtained using an optical dendrometer.

Trees are selected for detailed measurement using Grosenbaugh's "3-P" sampling scheme (1965). In stage five additional growth data are taken using remeasurement of USFS permanent plots in an effort to improve growth estimates and utilize an existing sampling scheme.

8.312.3 Sample size and allocation

Sample size and allocation decisions always have a degree of uncertainty associated with them. This is true of both the USFS system and the LANDSAT-based system. The USFS system sample size figures were based largely on experience gained on forests in the southern part of the state and hence may or may not reflect the actual number which might be necessary to achieve the desired precision. The LANDSAT-based system, on the other hand, has different uncertainties in addition to those associated with population characteristics. Further, in both cases planning has been based on volume as the one parameter of interest, but in fact both surveys estimate a number of parameters in addition to volume.

Based on preliminary results of the Plumas 1974 timber inventory, the population coefficient of variation for volume was estimated to be 125% based on a sample of 55 ground plots. Twenty USFS permanent plots selected at random showed a coefficient of variation (CV) for basal area to be about 60% so it is possible that the 125% figure is high. However, this figure was chosen as a reasonable basis for assumed population characteristics in these comparisons.

The figure of 150 ground plots for the USFS system in relation to the 125% CV for volume implies a gain due to stratification equivalent to a 75% reduction of the simple random sample size of 625 which would be required to meet necessary precision requirements. It is assumed that the LANDSAT-based system has achieved a similar gain. This degree of success in stratification has not been completely documented at this time; however, early indications are that as development of the system proceeds this level will be achieved. Further, there may be other factors relative to the costs of each stratification technique which will compensate for this assumption.

The remaining major component in the sample allocation problem relates to the double sampling link between large scale photo measurements and the ground measurements. In the longer term the whole design problem will be considered in a multistage framework; unfortunately, however, the time frame restricts the design to addressing certain major components separately. Details of the double sampling allocation model are given in Appendix I along with a tabular summary of sample sizes for given assumptions of CV, cost ratios, and correlations between ground and photo measurements. The preliminary results of the 1974 inventory indicate $CV=1.25$ and a ratio of photo measurement costs to ground measurement costs of 1:18. The actual correlation obtained was $r = .60$. However, certain measurement and training problems encountered as well

as the narrow time frame indicate that the 0.8 level of correlation is likely to be achieved as techniques improve. These parameters coupled with a 75% reduction due to expected gains in stratification would lead to a sample size of 74 ground plots and 418 photo plots. Similar figures could be completed for other precision levels if desired. This compares with the actual sample sizes for the 1974 inventory of 55 ground plots and 400 photo plots. Additionally, several variables are being used in the regression relationships relating ground and photo measurements rather than just volume alone. These may further reduce necessary sample sizes.

Sample size calculations for both ground plots (n) and photo plots (n') are listed below for four levels of allowable error at a one standard error level of confidence.

		Allowable Error (%)			
Sample size		5	10	15	20
	n	74	19	9	9
	n'	418	105	47	47

8.320 COMPARATIVE COSTS

8.321 Forest Service Sampling System

Costs for the existing timber resource inventory system were estimated from discussions with Forest Service personnel and from actual cost figures of recent (1974) USFS inventories in California. Table 1 summarizes the activities and costs of a hypothetical USFS timber inventory performed in the Plumas National Forest in 1974. The table groups activities and costs into four principal categories: stratification activities, ground data collection, data summary, and administration and overhead. Each category merits a brief discussion.

8.321.1 Stratification activities

The existing USFS sampling system would require that almost two-thirds of a Plumas inventory budget be spent on activities relating to sample stratification. A large part of this work would be performed by outside contractors. Table 1 breaks the stratification process into four phases. Pre-stratification activities are performed by the USFS and consist of resource photo procurement, preparation of background materials, and other minor tasks. The direct costs of this effort are minimal. The manual phase of stratification is performed almost entirely

TABLE 8-1: COSTS OF A USFS-STYLE TIMBER INVENTORY SAMPLING SYSTEM
PLUMAS NATIONAL FOREST, 1974*

		Performed by:	
		contractor	USFS
Stratification Activities			
Pre-stratification		\$ ---	\$No cost
Manual	(90 tm @ \$500 ea)	45,000	---
Digital: WRIS	(90 tm @ \$200 ea)	---	18,000
Site selection			1,000
Ground Data Collection (120 gp @ \$100 ea)		12,000	---
Data Summary			1,300
Subtotal		\$57,000	\$20,300
Administration	(10% on contracted costs, 30% on USFS costs)	---	11,800
Overhead	(3% on contracted costs, 30% on USFS costs)		7,100
Total Cost (Nearest \$1,000)			\$97,000

*Allowable error = $\pm 5\%$ at 1 standard error level of confidence (.68 probability)

tm= township maps
gp= ground plots

by a contractor. This consists of photo delineation and type map preparation. The USFS assists the contractor by providing aerial photos, existing timber stand maps, plot reference tags, aluminum nails, ground plot record sheets, a field handbook, and the time of a project supervisor. Contractor bids for stratification work in 1974 averaged about \$500 per township map. Since the Plumas National Forest covers 90 township maps, the phase would cost a minimum of \$45,000. USFS direct costs are included later with administration and overhead. The digital phase of stratification is performed by USFS staff. Information received from the contractor is digitized and entered into the WRIS mapping system. Costs here are about \$200 per township map, or about \$18,000 to fully map the Plumas. The site selection phase of the stratification process is performed by USFS staff. Direct costs for this phase are difficult to estimate since much of the site selection can be performed automatically. A minimal cost of \$1,000 is presumed.

8.321.2 Ground data collection

The USFS regularly contracts out their inventory plot location and measurement activities. Ground data collection costs in the 1974 California inventories varied widely depending upon the contractor, forest, and terrain. Costs are usually stated in dollars per ground plot, now based on a 5-point plot cluster system.¹ Contracted sampling costs in 1974 ranged from a low of around \$70 to a high of about \$125 per ground plot. Informed guesses as to how many ground plots the USFS would require to perform a current inventory on the Plumas range from a low of 90 to a maximum of 150. Total ground data collection costs thus could be as low as \$6,300 or as high as \$18,750. A middle-range figure of \$12,000 was chosen for the entry in Table 1. This is based on 120 ground plots at \$100 each. Note that the gains assumed for LANDSAT stratification (8.312.3) were conservatively biased in the other direction, using a USFS sample size of 150 ground plots.

8.321.3 Data summary

Following the stratification and ground data collection tasks, the information gathered must still be summarized into a form suitable for later reference and for use in developing timber resource management plans. This data summary task is performed by USFS staff and the associated costs are difficult to isolate. For the purposes of this study, existing system and LANDSAT-based system data summary costs are assumed equal at \$1,300.

1. The 1969 USFS Plumas inventory ground sampling was based on more expensive 10-point plot clusters.

8.321.4 Administration and overhead

In addition to the identifiable direct costs, the Forest Service sampling system incurs indirect costs in the form of administration expenses and overhead. Since the USFS could be expected to contract out about three-quarters of the costs of a Plumas National Forest inventory, indirect expenses might be lower than expected. University of California administration and overhead rates on the LANDSAT-based system are estimated at about 60 percent of direct costs. Using similar rates for the USFS system, administration costs equal \$12,000 and overhead is an additional \$8,000. This estimate is based on an equal administration-overhead expense split on USFS direct costs and a 10 percent - 3 percent split on contracted costs.

8.321.5 Total estimated costs

A summation of the above items brings the total estimate for a USFS-style inventory of the Plumas National Forest to \$97,000. This is necessarily a rough approximation, but if anything, it is biased to the low side. Ground data collection costs, for example, could be as much as 50 percent higher if the maximum estimate of plots is required.

8.322 LANDSAT-Based Sampling System

Cost estimates for the LANDSAT-based sampling system were developed along with the sampling methodology described in 8.312. Table 2 summarizes the results of this effort. Unlike the Forest Service cost information, estimated for only one sample size and level of precision, the LANDSAT-based cost data were easily translated into a variety of sampling size and precision levels. Moreover, cost figures for the LANDSAT-based system were available at a greater level of detail than for the USFS system. Disaggregated costs for the LANDSAT-based system subtasks are displayed in Appendix II. Costs for the basic activity categories shown in Table 2 are described briefly here.

8.322.1 Pre-photo/groundwork

Most of the costs within this category can be considered as "start-up" expenses. Appendix II lists nine subtasks: tape acquisition, tape reformatting, test area extraction, delineation and extraction of administrative boundaries, training of classifiers, discriminant analysis run, generation and selection of PSU's, and location of PSU's. Costs associated with these subtasks are for the most part unaffected by changes in the level of sampling precision. Table 2 assumes a multidade analysis, useful for enhancing LANDSAT information value and comparing timber stands over time. The addition of two extra dates triples the costs of tapes and increases the cost of computer operations. Multidade analysis adds about \$3,000 to the pre-photo phase, bringing total pre-photo costs to around \$7,100.

TABLE 8-2: COSTS OF A LANDSAT-BASED TIMBER INVENTORY SAMPLING SYSTEM
PLUMAS NATIONAL FOREST, 1974

Allowable Error*		+ 5%	± 10%	± 15%	± 20%
Ground Plots		74	19	9	9
Pre-Photo/Groundwork		\$ 7,100	\$ 7,100	\$ 7,100	\$ 7,100
Aerial Photo/Interpretation		4,200	3,000	2,500	2,500
Ground Data Collection (\$185/gp)		13,700	3,500	1,700	1,700
Data Summary		1,300	1,300	1,300	1,300
Map Generation (90 tm @ \$90 ea)		8,100	8,100	8,100	8,100
Subtotal		\$34,400	\$23,000	\$20,700	\$20,700
Administration (27%)		9,300	6,200	5,600	5,600
Overhead (30.2%)		10,400	7,000	6,300	6,300
Total Cost (nearest \$1,000)		\$54,000	\$36,000	\$33,000	\$33,000

*Allowable error at 1 standard error level of confidence (.68 probability)

tm= township maps
gp= ground plots

This additional amount, however, is designed in part to reduce the cost of subsequent steps by reducing the total number of lower stage sample units required. These reductions are facilitated by improved stratification accuracy.

8.322.2 Aerial photo interpretation

Aerial photography acquisition and interpretation costs were developed from a sample of 55 ground plots. Photo acquisition costs are considered as relatively fixed, while photo interpretation costs vary in proportion to the number of ground samples needed for each level of precision. Total costs for this category are about \$4,200 at a 5 percent allowable error level.

8.322.3 Ground data collection

Consisting of mileage, wages, and per diem charges, costs in this category are directly related to the number of ground plots sampled. For 55 ground plots, data collection costs were \$185 per plot. This is much above the \$100 figure estimated for the USFS plots, but reflects a high mileage figure and the use of a dendrometer in place of less accurate timber volume tables. At the \$185 rate, ground data collection costs for 74 plots approach \$13,700.

8.322.4 Data summary and map generation

Both data summary and map generation costs remain constant over varying levels of precision. Costs for the LANDSAT-based data summary amounted to \$1,300, half of which were report preparation and reproduction. Actual map generation costs were below \$45 per township map, but to assure comparability an inflated unit cost of \$90 per map is used here. Even this figure represents a considerable savings over the USFS map-production system where WRIS maps were estimated at \$200 each. The total cost for 90 township maps is \$8,100.

8.322.5 Administration and overhead

Indirect costs in the LANDSAT-based system are applied fully to all the above cost categories. At University of California rates, administration and overhead charges add 57.2 percent to direct costs. For a 5 percent allowable error level, administration and overhead together account for \$20,000.

8.322.6 Total estimated costs

Estimated LANDSAT-based system costs, when rounded to the nearest \$1,000 total \$54,000 for a 74-ground plot sampling effort at a 5 percent allowable error level. Costs for lower levels of precision stabilize at around

\$33,000. In contrast to the USFS-style inventory system costs, which were purposely estimated on the low side, the total costs of the based system are biased in the opposite direction. The inclusion of multirate analysis capability, extensive training for image analysts, high labor and mileage rates, and added costs for map generation insures against understating the costs of the LANDSAT-based inventory system.

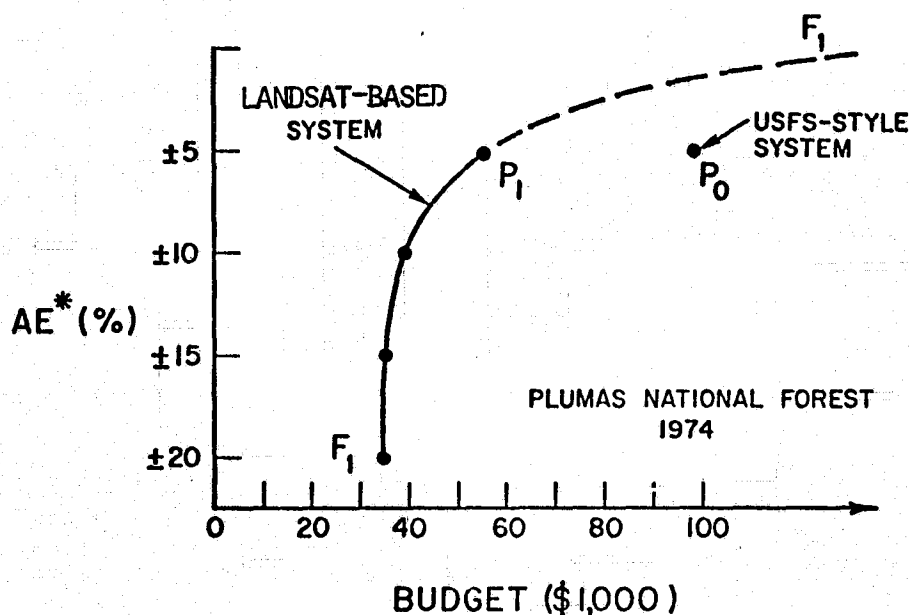
8.400 RESULTS AND CONCLUSIONS

The foregoing information facilitates a direct comparison of the two inventory systems on a cost-effectiveness basis. Figure 2 compares the two systems in a manner analogous to Figure 1. Tables 1 and 2 supply the relevant cost and capability data for each system.

Point P_0 in Figure 2 represents one production possibility of the existing timber inventory system. Here, total costs for a USFS-style inventory of the Plumas National Forest in 1974 are estimated at \$97,000. This budget amount is sufficient to produce inventory information with an allowable error of ± 5 percent at a level of confidence of one standard error (0.68 probability).

Four production possibilities of the LANDSAT-based inventory system are represented along frontier F_1F_1 in Figure 2. Each point portrays the budget required to attain a given level of inventory precision. Point P_1 , at the ± 5 percent allowable error level, is directly comparable with point P_0 . Here, the LANDSAT-based system shows a \$43,000 (or 44%) advantage over the existing timber inventory system. On a cost per acre basis, the LANDSAT-based inventory at 4.7¢ per acre compares favorably with the USFS-style inventory at 8.4¢ per acre.

FIGURE 8.2: COST-CAPABILITY COMPARISON OF TIMBER INVENTORY SAMPLING SYSTEM



* ALLOWABLE ERROR AT 1 STANDARD ERROR LEVEL OF CONFIDENCE

The LANDSAT-based inventory system derives its advantage from two principle sources of cost savings: (1) initial stratification procedures, and (2) low-cost map generation. Automatic processing substantially reduces the amount of manual effort required in both activities. Initial stratification in the existing inventory system is performed mainly by human interpreters using resource photography and previously-produced forest type maps. The LANDSAT-based system, by utilizing a cost-effective blend of automatic processing techniques and computer-training inputs by human interpreters, allows substantial reductions in stratification and map generation.

The integration of automatic processing with stratification activities in the LANDSAT-based system also enables the generation of low-cost, digitized township maps. This study found that color-coded LANDSAT-based maps could be produced for one-quarter to one-half the cost of comparable black-and-white USFS WRIS township maps. The regular availability of LANDSAT imagery enhances the value of this type of map for use in updating wildland data bases.

In spite of the cost-effectiveness advantages promised by an LANDSAT-based timber inventory system, much additional investigation remains beyond the scope of this study. A more comprehensive analysis would include at least the tasks mentioned below.

(1) An examination of assumptions. Some of the assumptions made in this study require additional attention. For example, it was assumed that both systems are currently operating upon their respective cost efficiency frontiers. In actuality, the efficiencies of both systems can probably be improved; but the early-development nature of the LANDSAT-based system suggests the opportunity for greater improvement. Assumptions regarding equivalent gains in stratification should similarly be scrutinized. There is a good chance that LANDSAT will provide even higher stratification gains after procedures are developed better relating LANDSAT and ground-based data. This is due to LANDSAT's consistency and acre-by acre resolution ability. Assumptions about output comparability also require examination. It may be that an LANDSAT-based inventory system is capable of producing an output which adds new dimensions to forest management planning practices. Increased inventory frequency could be an example here. Finally, capital costs could be examined in addition to operating costs. User agencies must also consider the start-up costs of implementing a potentially more efficient inventory system.

(2) An examination of sensitivity issues. The ability to identify those areas that most affect a system's cost and capability relationships is an essential part of a complete analysis. For example, it would be useful to know how the cost-effectiveness of an LANDSAT-based inventory system is affected by changes in forest size or heterogeneity. Additional case examples are required for a thorough investigation of the sensitivity issue.

(3) An examination of the benefits issues. Cost-effectiveness theory measures benefits in terms of cost savings. To better forecast the impact of investment in a new project or program it is useful to carefully analyze the resulting net benefits and beneficiaries. From this study, it can be expected that the primary benefits of a LANDSAT-based system would be cost savings to user agencies. Such organizations could apply these savings to extend the capability of the system, to develop other subject areas within the inventory design such as soil characteristics, or to initiate or expand other desired programs. Stratification of private as well as public lands is an example of capability extension. Another source of benefits would stem from the system's ability to deliver resource information and associated acquisition cost data not otherwise available. Inplace mapping of timber volume, type, and condition class and more efficient allocation of sample units are examples of additional information types. A thorough examination of benefits issues would help place values on such benefits.

(4) An examination of implementation issues. Cost-effectiveness analysis is but one tool in the process by which new technologies become applied technologies. Many other issues must be examined during the implementation process. Of foremost importance is familiarity with the decision and administrative structure of the user agency. An LANDSAT-based timber inventory system may be able to offer significant cost savings to user agencies, in terms of both the user's operating and capital costs, but non-cost considerations may prove more important. An understanding of and collaboration with the user agency's organizational dynamics is a necessary prerequisite in achieving a successful integration of a LANDSAT-based system with existing USFS inventory systems.

Appendix I: Optimum Sample Allocation in Double Sampling for Regression

1. References: Raj, 1968, Sampling Theory and Cochran, 1963, Sampling Techniques.
2. The population variance for the double sampling estimator is given as

$$V(\bar{y}_{ds}) = \frac{s_y^2 (1-\rho^2)}{n} + \frac{\rho^2 s_y^2}{n'} = \frac{s_y^2}{n} [1-\rho^2(1-\frac{n}{n'})] \quad (1)$$

The cost function is assumed to be

$$TC = Cn + C'n' \quad (2)$$

Notation is as follows:

$$s_y^2 = \frac{1}{n-1} \sum (y_i - \bar{y})^2$$

ρ = correlation coefficient between y and x, the auxiliary information

n' = sample size for large sample where only x is measured

n = sample size for small sample where x and y are measured

TC = total variable cost of sampling

C = cost of making an observation for the small sample

C' = cost of making an observation for the large sample

If a desired precision level D is specified, we would like to minimize TC . Using Lagrangian multipliers:

$$\min \pi = Cn + C'n' + \lambda^2 \left[\frac{s_y^2 (1-\rho^2)}{n} + \frac{\rho^2 s_y^2}{n'} - D \right] \quad (3)$$

$$\frac{\partial \pi}{\partial n} = C - \lambda^2 \frac{s_y^2 (1-\rho^2)}{n^2} \quad (4)$$

$$\frac{\partial \pi}{\partial n'} = C' - \lambda^2 \frac{\rho^2 s_y^2}{(n')^2} \quad (5)$$

$$\frac{\partial \pi}{\partial \lambda^2} = \frac{s_y^2 (1 - \rho^2)}{n} + \frac{\rho^2 s_y^2}{n'} - D \quad (6)$$

Setting (4) and (5) equal to zero and combining terms

$$\lambda^2 = \frac{C n^2}{s_y^2 (1 - \rho^2)}$$

$$\lambda^2 = \frac{C' (n')^2}{\rho^2 s_y^2}$$

Then,

$$\lambda^2 = \frac{C n^2}{s_y^2 (1 - \rho^2)} = \frac{C' (n')^2}{\rho^2 s_y^2}$$

$$\lambda^2 = \frac{C n^2}{C' (n')^2} = \frac{s_y^2 (1 - \rho^2)}{s_y^2 \rho^2}$$

$$\lambda^2 = \frac{n^2}{(n')^2} = \frac{C' (1 - \rho^2)}{C \rho^2}$$

$$\lambda = \frac{n}{n'} = \sqrt{\left(\frac{C'}{C}\right) \left(\frac{1 - \rho^2}{\rho^2}\right)} \quad (7)$$

From (1),

$$\frac{D^2}{t^2} = \frac{s_y^2}{n} [1 - \rho^2 (1 - \lambda)] \quad (8)$$

where $\frac{D^2}{t^2}$ = Desired Sampling Variance

$$\text{or } D = t \sqrt{V(\bar{Y}_{ds})}$$

Then we have

$$n = \frac{t^2 s_y^2}{D^2} [1 - \rho^2 (1 - \lambda)] = [1 - \rho^2 (1 - \lambda)] n_{srs}$$

$$\text{where } n_{\text{SRS}} = \frac{t^2 CV^2}{2 AE},$$

$$n = n_{\text{SRS}} [1 - \rho^2(1 - \lambda)] \quad (9)$$

3. Double sampling is more desirable than simple random sampling according to Raj (p. 151), if

$$\rho^2 > \frac{4cc'}{(c+c')^2}$$

For the Plumas, assuming $\frac{c'}{c} = \frac{1}{10}$ maximum

$$\frac{(4)(1)(10)}{(10+1)^2} = .33 = \rho^2, \text{ So if } \rho \geq .57, \text{ double sampling is preferred.}$$

4. Given ρ , CV, AE, C' , and C sample size may be determined using equations given above.

$$\lambda = \frac{n}{n'} = \sqrt{\left(\frac{c'}{c}\right) \left(\frac{1 - \rho^2}{\rho^2}\right)} \quad (10)$$

$$n = \frac{t^2 CV^2}{AE^2} [1 - \rho^2(1 - \lambda)] \quad (11)$$

$$n' = n/\lambda \quad (12)$$

5. For the Plumas 74 inventory a series of calculations was made with various assumptions for ρ , CV, C' and C . The desired precision level throughout is $\pm 5\%$ at the 1 standard error probability level (Forest Service Standard). Table 1.1 below summarizes the results of these calculations. Final sample size was selected as $n' = 400$ and $n = 55$.

Table 1.1 Sample Size/Allocation Summary (n/n')

	$C'=1, C=10$		$C'=1, C=15$		$C'=1, C=18$	
CV	$\rho=.8(\lambda=.2372)$	$\rho=.9(\lambda=.1532)$	$\rho=.8(\lambda=.1936)$	$\rho=.9(\lambda=.1251)$	$\rho=.8(\lambda=.1768)$	$\rho=.9(\lambda=.1192)$
.50	51/215	31/205	48/250	29/232	-	-
.55	62/261	38/248	59/305	35/282	-	-
.80	131/552	80/524	124/640	75/596	121/685	73/634
1.25	-	-	-	-	296/1673	177/1546

**Appendix II: Detailed Costs of LANDSAT-Based Timber Resources
Inventory System, Plumas National Forest, 1974**

PRE-PHOTO/GROUNDWORK (Multidate Analysis: 3 dates)

Tape Acquisition	\$ 1,080
Tape Reformatting	
Tape 3 tapes/date @ \$7.75 ea	70
Computer Time 1 hr/date @ \$40/hr.	120
Operator 1½ hrs/date @ \$5/hr	23
Test Area Extraction	
Tape 3 tapes/date @ \$7.75 ea	70
Computer 1 hr/date @ \$40/hr	120
Operator 1½ hrs/date @ \$5/hr	8
Delineation/Extraction of Stratification (initial)	
Photo Reduction of Map	16
Digitizer with Operator 2 hrs @ \$43/hr	86
LSR Fit of Co-ordinates: computer 6 runs/date @ \$1.80/run	65
operator 8 hrs/date @ \$3/hr	72
Computer Mask Generation: computer	38
operator 3 hrs/date @ \$5/hr	45
Delineation/Extraction of Administrative Boundaries	
Photo Reduction of Map	16
Digitizer with Operator 8 hrs @ \$43/hr	344
LSR Fit of Co-ordinates: computer 9 runs/date @ \$1.80/run	50
operator 10 hrs/date @ \$3/hr	90
Computer Mask Generation: computer	13
operator 3 hrs @ \$5/hr	15
Training of Classifier (~60 classes/strip; 3 strips/base date)	
Computer Display terminal 24 hrs @ \$40/hr	960
Image Analysts 50 hrs @ \$6/hr	300
Statistical Analysis: computer (LBL)	75
operator 30 hrs @ \$3/hr	90
Selection of Channels & Classes 20 hrs @ \$5/hr	100

Discriminant Analysis Run		
Multidate: computer 9 runs		\$1,920
operator/analyst 50 hrs @ \$7.60/hr		380
Generation and Selection of PSU's		
Computer 3 hrs @ \$40/hr		120
Analyst 4 hrs @ \$3.40/hr		14
Location of PSU's (for aerial photography)		
Computer 10 hrs @ \$40/hr		400
Analyst 80 hrs @ \$5/hr		400
		<hr/>
		\$7,100

AERIAL PHOTOGRAPHY/INTERPRETATION (74 ground plots)

Photo Acquisition

Aircraft	25 hrs @ \$32/hr	\$ 800
Pilot	32 hrs @ \$ 6/hr	192
Photographer	32 hrs @ \$3.40/hr	109
Film	60 rolls @ \$3.60/roll	216
Processing	60 rolls @ \$1.90/roll	114
Printing	ave 30 images/roll @ \$.63/5" X 7" print (1800 prints)	1,134

Photo Interpretation

Image Analyst 360 hrs @ \$3.40/hr	1,650
	<hr/>
	\$4,215

GROUND DATA COLLECTION (74 Ground Plots)

Travel

Mileage 6,180 @ \$.15/mile \$ 930

Crew

Wages 1,980 hrs @ \$3.86/hr (62 days; 4 men) 7,650

Per Diem 5,100

\$13,680

DATA SUMMARY AND MAP GENERATION

Computer Analysis, Ground and Photo Data \$ 280

Combining LANDSAT and Ground Data 8 hrs @ \$5/hr 40

Generation of Summary Statistics 16 hrs @ \$5/hr 80

Generation of Maps 90 township maps @ \$90 ea 8,100

Report Preparation and Reproduction 650

Computer Time 250

\$ 9,400

Subtotal \$34,395

ADMINISTRATION (27%) 9,287

OVERHEAD (30.2%) 10,387

Total Cost \$54,069

CHAPTER 9

SPECIAL STUDIES

No. 1: Atmospheric Effects in Image Transfer

Co-Investigators: K. L. Coulson and
R. L. Walraven,
Davis Campus

**No. 2: The Potential Usefulness of Earth Resources
Technology Satellites in Relation to the
Management of Earth Resources and the
Preservation of Man's Environment**

Co-Investigator: Robert N. Colwell,
Berkeley Campus

**No. 3: Statement Before the Subcommittee on Space
Science and Applications of the Committee
on Science and Astronautics, U.S. House of
Representatives, Ninety-third Congress,
Second Session**

Co-Investigator: Robert N. Colwell
Berkeley Campus

**No. 4: Input Quality Encoding of Multispectral
Data**

Co-Investigator: V. Ralph Algazi, Davis and
Berkeley Campuses

**No. 5: Utilization and Assessment of Remote Sensing
Data**

Co-Investigator: Ida R. Hoos
Berkeley Campus

**No. 6: Statement Before the Interior Subcommittee of
the Appropriations Committee, U.S. Senate 94th
Congress**

Co-Investigator: Robert N. Colwell
Berkeley Campus

CHAPTER 9

SPECIAL STUDIES

Special Study No. 1: Atmospheric Effects in Image Transfer

Co-Investigators: K. L. Coulson and R. L. Walraven,
Davis Campus

I. Introduction

Evidence is being accumulated that the polarization of the light reflected from natural surfaces can be used to good advantage for characterization of the surfaces and for discriminating among the different types of surfaces of most interest in remote sensing applications. For instance, the small number of measurements available show that broad-leaf plants polarize more strongly than do members of the grass family. Similarly, the degree of polarization of the reflected light is affected by the amount of wax on the leaf surface, the roughness of the leaf, any small hair-like structures of the leaf, and the general structure of the canopy. These are all parameters which are useful in discriminating among different types of vegetation.

The most convenient method of investigating the polarization characteristics of a scene is probably by the use of a television display. The advantages of this type of presentation over the photographic method is that, being essentially instantaneous, the television system is not subject to the delays necessary in developing negatives or prints, the signals are readily deciphered in terms of the physical quantities involved, and they can be introduced directly into a computer for digital enhancement or other manipulation of the data. This last factor is of particular value for polarization sensing, as the degree of polarization and orientation of the plane of polarization of the light are both derived from computations based on two or more images of the same scene. Electronic storage of the images, which is most conveniently accomplished for the sequential type signals of a television system, permits the type of computer manipulation necessary for deriving the state of polarization of the light from the scene of interest.

Another method of obtaining polarization measurements from natural surfaces is by the use of a polarizing radiometer. This is the most satisfactory method of investigating the reflection properties in detail, and it has already been extensively used on this project to yield valuable data on surface properties. The method is, however, not well adapted to determining the polarization properties of the type of image most useful

in remote sensing applications. The radiometric method is slow, giving data at only one resolution point at each instrument setting, and it would take an inordinate amount of time to build up the image of a scene, element by element. In addition, the equipment is expensive, somewhat complicated, and not readily portable. The television-computer combination, on the other hand, makes use of the tremendous technology which has been built up by the electronics industry to avoid the main deficiencies of both the photographic and radiometric methods. Thus, it is most adaptable to the demanding task of extracting from an instrument response signal all of the intensity and polarization information contained in an image received at a remotely located sensor.

This is not to say, of course, that the television-computer combination is without difficulties for the purpose. The response of television tubes is non-linear with intensity, a fact which requires careful calibration and correctional procedures, and fatigue effects of the tube may be serious in some cases. In addition, digital processing of the signals is demanding in both computer capability and computer time. This latter factor is not particularly serious in the present study, however, as a relatively sophisticated computer system is readily available on the project.

11. Preliminary Results

In order to check out the concept of a video polarizer system for use in remote sensing, a somewhat primitive system has been built up and used for obtaining some low resolution images in which polarization effects are demonstrated. The preliminary nature of the results should be emphasized. Not only is the resolution low, but also some of the electronic components introduced sufficient noise into the signal to further degrade the image. These deficiencies can be eliminated, however, by improved electronic components and signal processing, and indeed these improvements are the major objective of the final phase of the project. As will be seen below, the basic concept of the video polarizer system is a sound one, the results obtained already show that the combined polarization and intensity fields carry much more information than does the intensity field alone, and the low level of effort anticipated for our part of this integrated study during the next year (as we conclude our "phasing out" stage), is expected to result in an operable system for remote sensing applications.

The final design of the system has been modified somewhat from that shown in a previous report to that shown in Fig. 1. The polarizer is set at different orientations in front of the television camera, an image being taken at each setting. At least three different polarizer settings are necessary to derive all of the polarization information, but four settings will provide some redundancy in the data and is the number used so far. The scan from the television camera is processed through various electronic modules, and is eventually presented to the

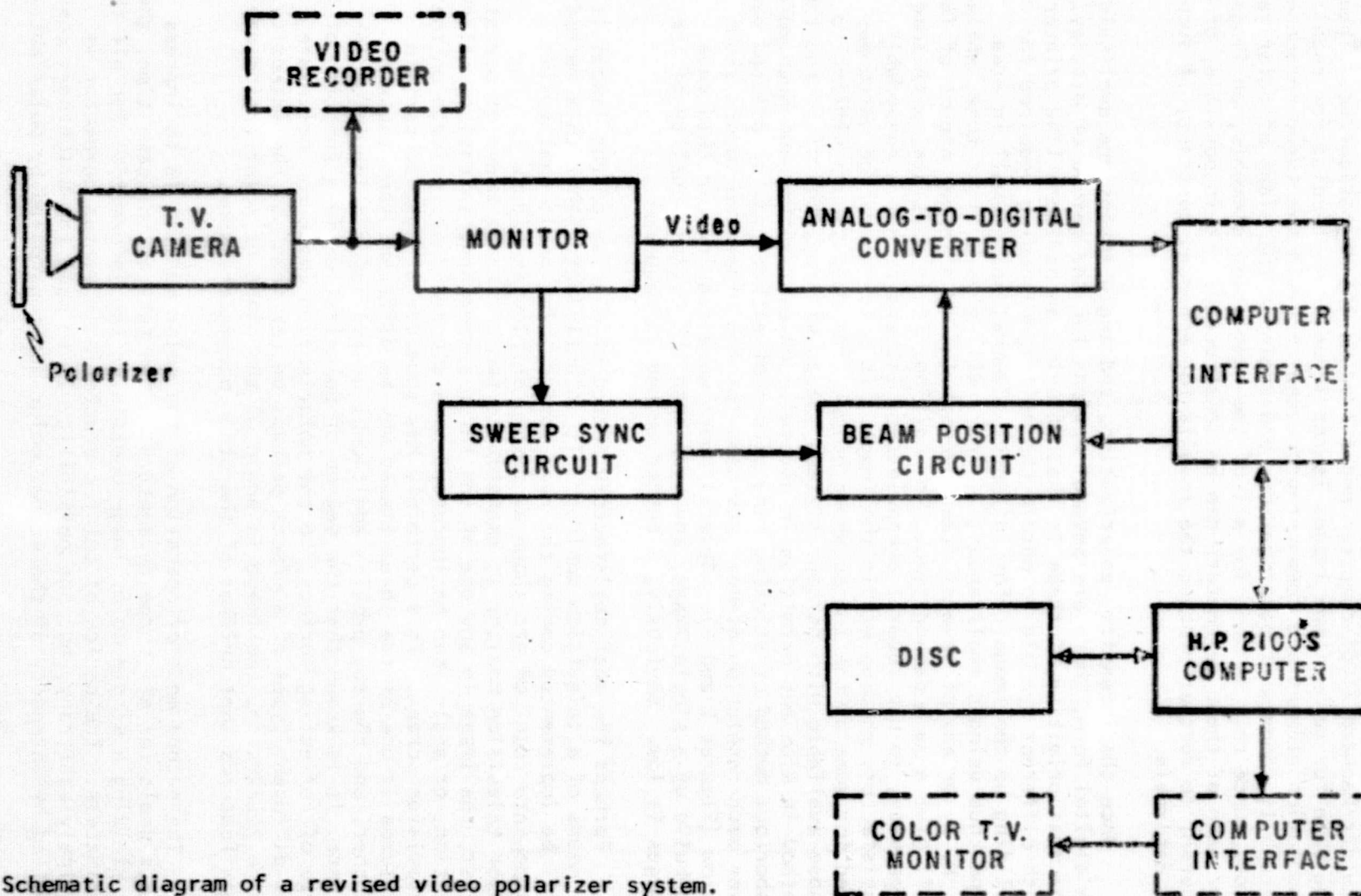


Fig. 1 Schematic diagram of a revised video polarizer system. Dashed lines indicate components that will be included during the next reporting period in order to display the polarized images by means of a color television monitor.

Hewlett-Packard 2100S computer and stored on the magnetic disc. Then the data for each of the images is retrieved from the disc for each resolution element and computer-processed to yield the three parameters intensity, degree of polarization, and angle of the plane of polarization. Once this is done for all of the resolution elements, an image for each of these parameters can be constructed. It is possible, of course, to further process the results for enhanced contrast, if such is desirable.

Once the intensity, polarization, and angle images are available in digital form, there are several options for the method of display. The most primitive of these is that of using an ordinary line printer with different symbols to obtain the half-tone shading required for building up the image. For instance, a comma, being small in area (and thus using a small amount of ink), will give a light tone, while a W, M, B, or any of several other letters (using a larger amount of ink) will give a much darker tone. In addition, it is possible, with some ingenuity, to use several overprints of letters to get a reasonably satisfactory shading within the image. This is the method which was used for some of the images shown below. The results are similar to those available with perhaps sixteen shades of gray, but of course the method is slow and primitive in general. An even slower and much more laborious method of sticking tiny pieces of either gray or colored paper over each resolution element was used for the other two images shown below (Figures 2 and 6). Several hours were required in this case to build up a single image, and even then the overall quality of the images is low. Obviously, a better method is required.

Perhaps the most satisfactory method of display of the images is by means of a television monitor. It is anticipated that this method will be implemented during the next period. The additional system components required are shown as dashed entries in Figure 1. The color television monitor is amenable to two different modes of operation. First, the image in any one of the three parameters, intensity, polarization, or angle, can be impressed as a black-and-white image on the television screen. This certainly has some usefulness, as certain features in one of the three images may be different from those of another, and thereby provide additional useful information. For instance, it is known that the degree of polarization is a function of the type of reflecting surface, so the polarization image can delineate the different types of surfaces perhaps better than can the intensity image. Likewise, the image in angle of the plane of polarization may show features that neither of the other parameters show.

The second mode of operation of the color monitor is to impress the signals for all three parameters on the tube at the same time, thereby yielding a single color image containing the information for all three parameters. The choice of color characteristic versus parameter is entirely arbitrary, but one possibility is to have the brightness controlled by intensity of the scene, color hue controlled by polarization

of the scene, and color saturation controlled by the angle of the plane of polarization of the scene. Perhaps experience will show that some other combination is preferable for interpretation of various features of the scene, but since all of the signals are of the same digital form, there would be complete flexibility in the choice of presentation.

As mentioned above, some very preliminary results obtained from a primitive system are shown in the following low resolution images. The choice of an ordinary telephone as the subject was motivated by the fact that black plastic is a good polarizer, that the contoured surface of a telephone provides many different angles of the plane of polarization, and that the telephone is a familiar object.

A different rendition of the intensity image, in which the shading is obtained by gluing tiny pieces of paper made of eight different shades of gray on the resolution elements is shown in Fig. 2. In spite of the large amount of effort expended in constructing this image, the shading is not very uniform and the resolution is still low. The contrast, however, is better in this case than in those shown below.

The images of Figures 3, 4, and 5 were obtained from the parameters intensity, degree of polarization, and angle of the plane of polarization, respectively. They were made by judicious selection of the alpha-numeric symbols of a line printer to give the shading necessary. Although the resolution is low and the signal was somewhat noisy, there is no difficulty of recognizing the object as a telephone, at least in the intensity and polarization images of Figures 3 and 4. The image in angle of Fig. 5 is not quite so distinct, although even there the general outlines are evident. A careful look at the images reveals that not all of the images show the same features, a fact which emphasizes the basic value of the method. For instance, the telephone cord is more evident in the intensity image of Fig. 3; many more details of the dial section of the telephone are shown in the polarization image of Fig. 4; and details in or near the transmitter section (and also in the lower right section of the base) are best seen in the plane of polarization image of Fig. 5, even though the latter image suffers from noise. It should be realized in this context that in ordinary remote sensing methods, only the intensity image would be available.

An attempt to display all of the polarization information (Figures 4 and 5) in a single composite is shown in Figure 6. Here the structure was built up by gluing tiny pieces of colored plastic on the resolution elements. The degree of polarization is represented by the saturation of the colors and the angle of the plane of polarization by the hue. For instance, the light colored area to the right of the telephone represents the low polarization of the background, whereas the saturated color (deep red) of the earpiece represents a high degree of polarization. The change of color from red, yellow, green, blue, violet shows a rotation of the plane of polarization from 0 to 180° with respect to the vertical direction. This angle is dependent mainly on aspect angle of the surface.

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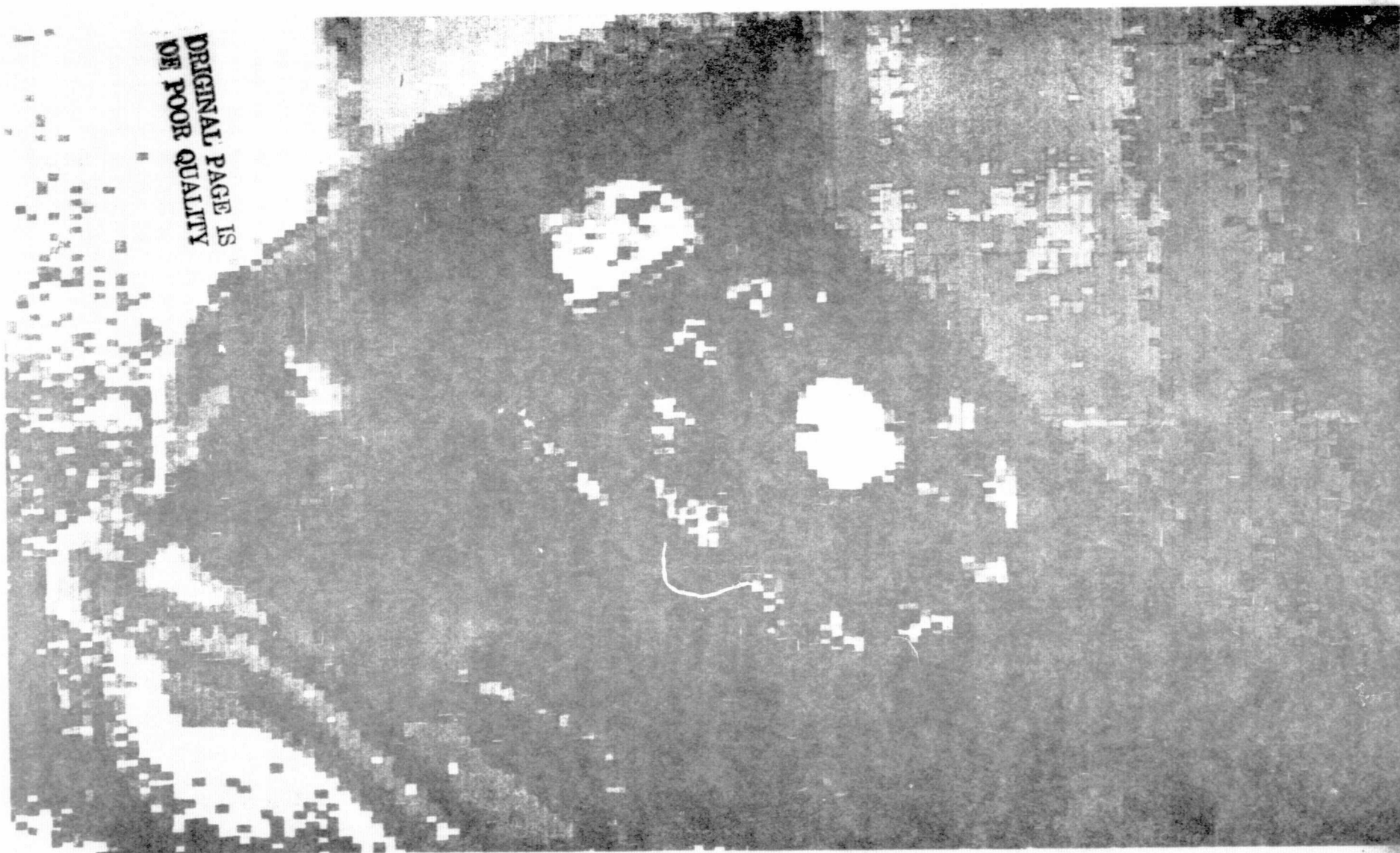


Fig. 2 A low resolution image obtained by computer processing of the intensity component of the signal from the video polarizer.

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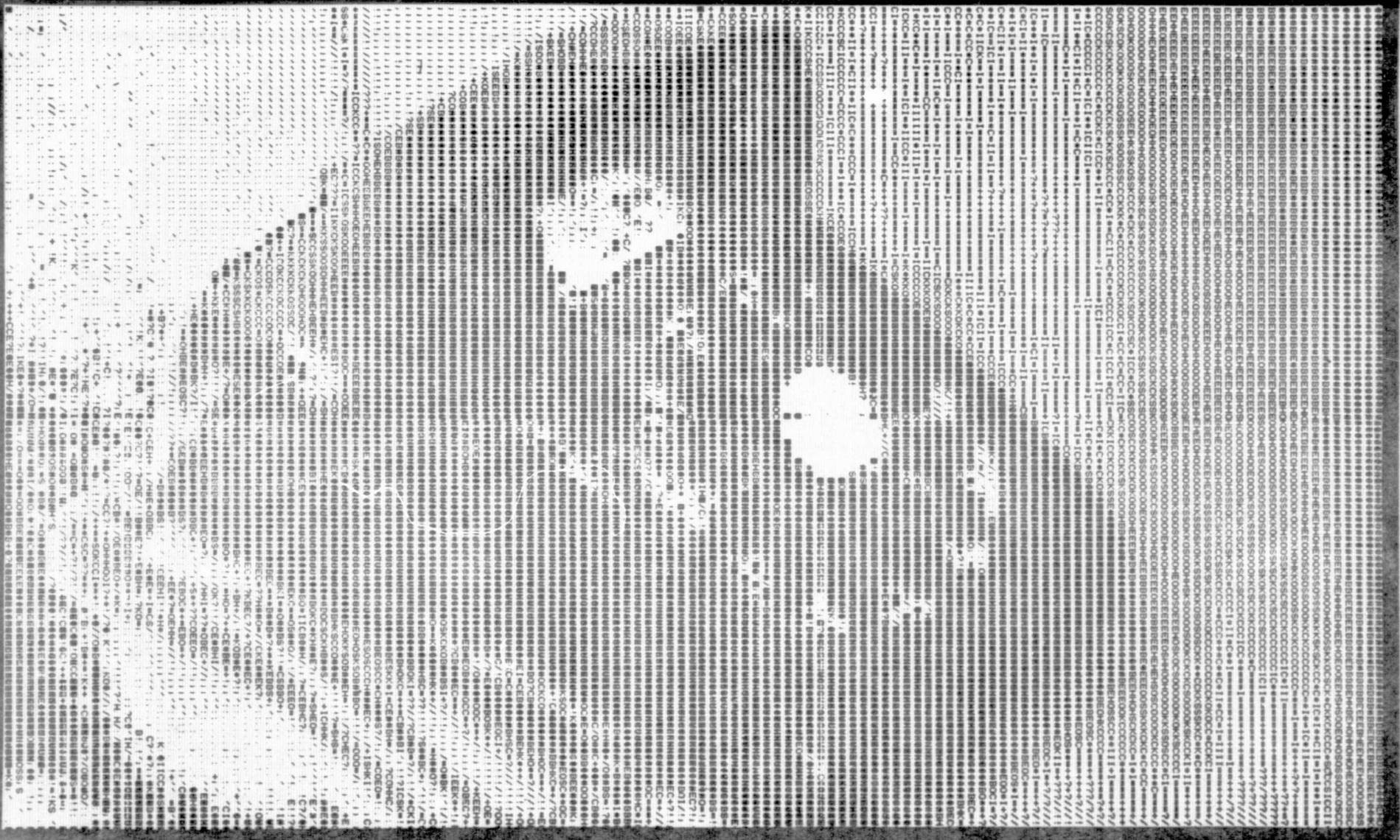


Fig. 3 A low resolution image obtained by a line printer readout of the intensity component of the signal from the video polarizer.

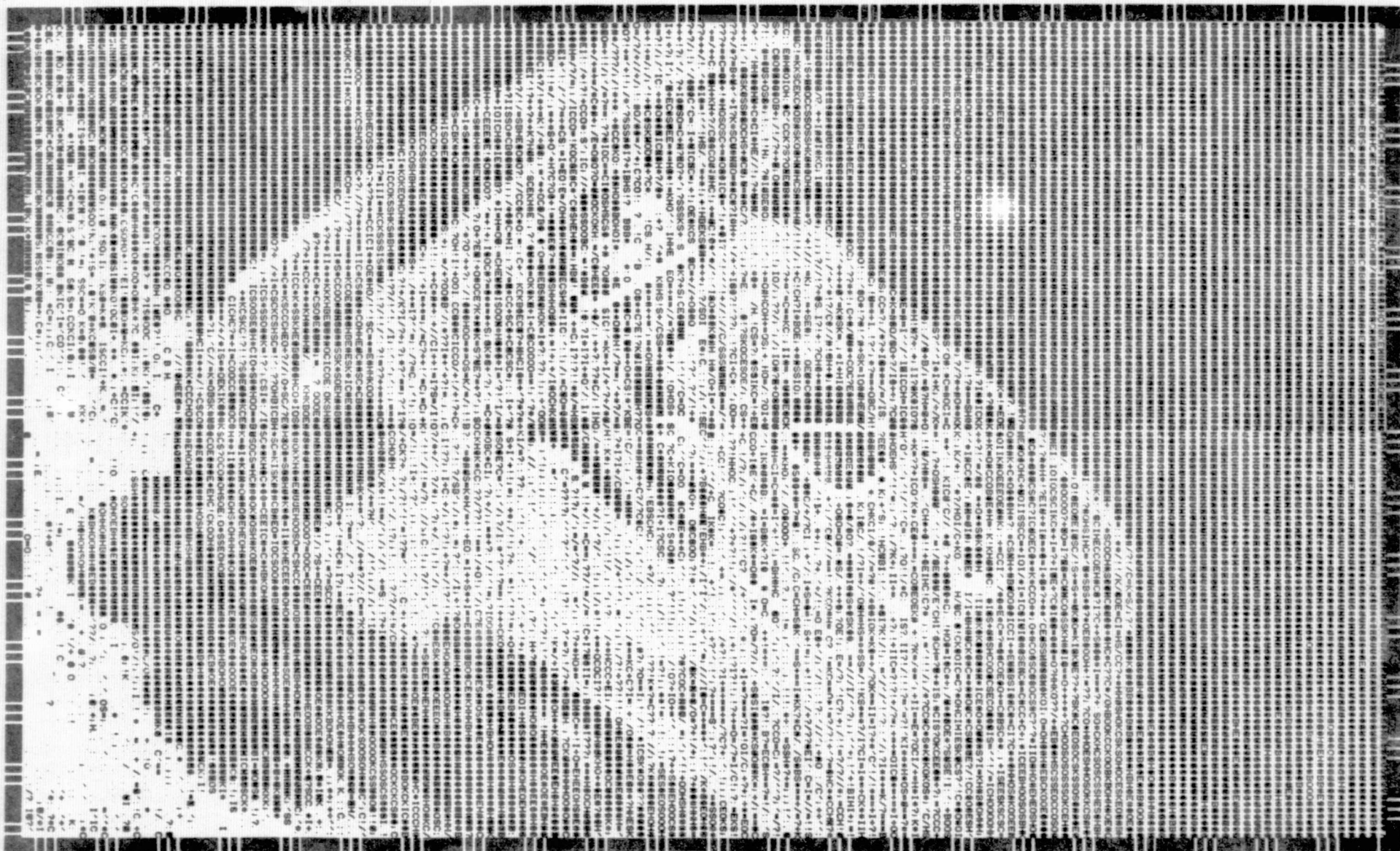


Fig. 1 A low resolution image obtained by a line printer readout of the polarization component of the signal from the video polarizer. (Only the polarization contributes to this image.)

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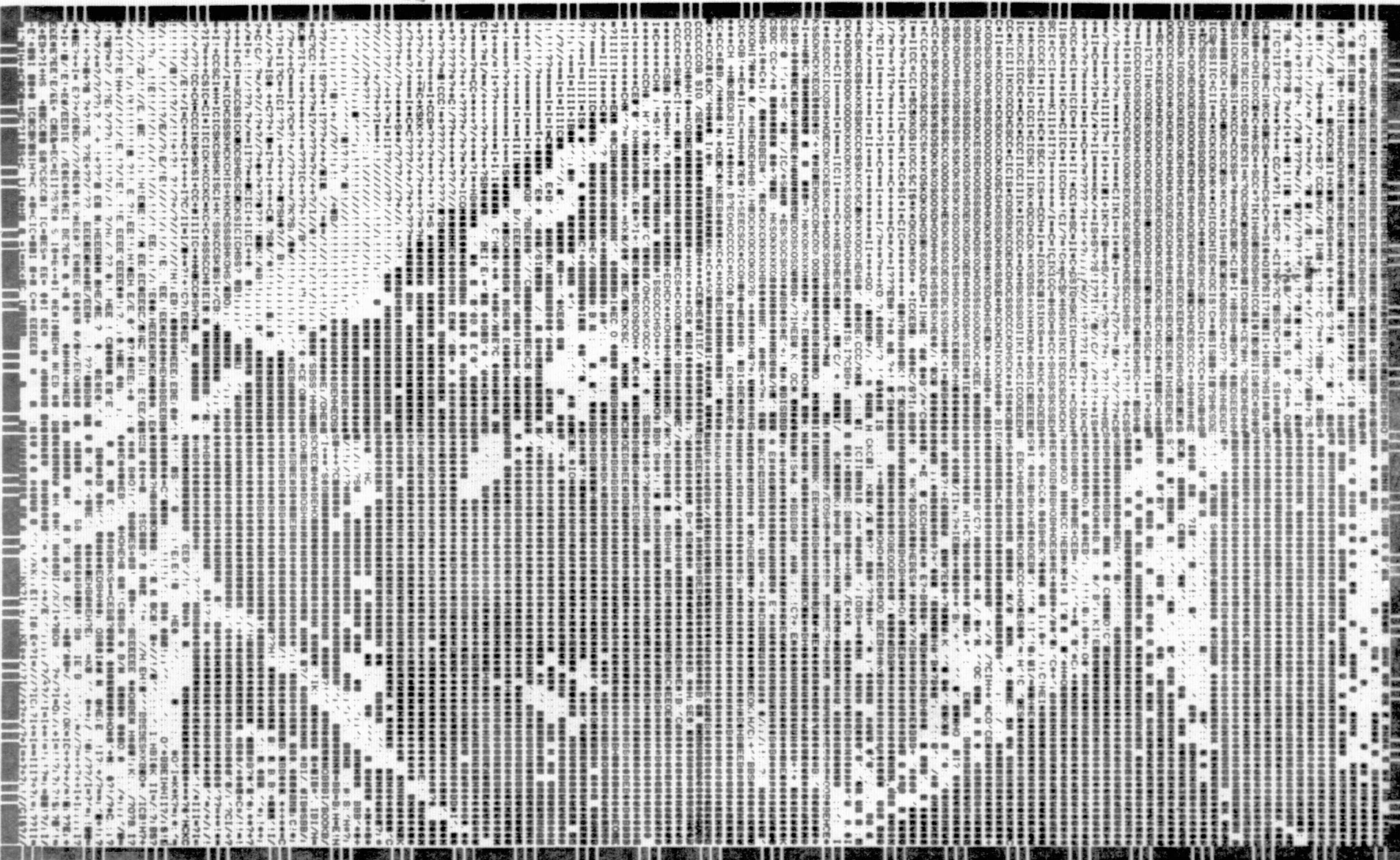


Fig. 5 A low resolution image obtained by a line printer readout of the plane of polarization component of the signal from the video polarizer. (Only the orientation of the plane of polarization contributes to this image.)



Fig. 6 A composite image obtained by color coding the degree and plane of polarization components of the signal from the video polarizer. The hue (red, blue, green, etc.) represents the plane of polarization, while the color saturation represents the degree of polarization.

The colored image suffers from the resolution and noise problems mentioned above, plus some additional ones of its own. Over the area of the telephone dial, for instance, the polarization field is so packed full of information, due to small elements which polarize highly, that a low resolution image becomes somewhat broken up. This is true also in other areas as well. Another practical difficulty is that it was impossible to get as many colors and shades of plastic as needed to represent all of the variations of hue and saturation. In spite of these difficulties, however, a careful analysis of Fig. 6 shows many subtle differences which can be interpreted in terms of the reflection characteristics and aspect of the various surfaces of the telephone and background. We emphasize again that this is strictly a polarization image, and is independent of intensity.

III. Future Plans

In order to further develop the method of introducing polarization effects into remote sensing applications, practically all of the effort in this final and low effort phase of the investigation will be put on the video polarizer system. The provision of a color television monitor, properly interfaced to the computer system, will greatly minimize the resolution problem which plagues the images shown above, and density gradients will be smooth and uniform. All three of the parameters can be displayed as intensity, hue, and saturation of the colors on the face of the tube, thereby presenting a tremendous amount of information in a form which is readily transferred to the human brain. All of the laborious and time consuming effort which went into building up the images shown above will be eliminated, and the images can be conveniently manipulated as required. A hard copy of any desired image can be obtained by photographing the face of the television tube.

The main hardware items which we still need in order to develop the video polarizer system to an operational status are a color television monitor (together with the necessary interfacing electronics), and the video recorder shown in the schematic diagram of Fig. 1. In addition, a considerable amount of effort will have to be put into the design, fabrication, and interfacing of the electronic modifications necessary to make the system truly operational. Both of these items are outlined in the proposed budget. At the end of the project period, it is anticipated that the system will have been used in an operational mode to collect data in realistic remote sensing applications to demonstrate its usefulness in a convincing manner.

IV Proposed Schedule

The following are the principal events anticipated for the final period of this part of the research grant:

Task	Date				
	5/75	8/75	11/75	2/76	5/76
Start of final research year (for this part of project)	▲				
Develop final design of video polarizer	←→				
Purchase required additional components		←→			
Fabrication and checkout of system			←→		
Interim report			▲		
Acquisition and analysis of remote sensing images				←→	
Final report					▲

SPECIAL STUDY NO. 2

THE POTENTIAL USEFULNESS OF EARTH RESOURCES TECHNOLOGY SATELLITES* IN RELATION TO THE MANAGEMENT OF EARTH RESOURCES AND THE PRESERVATION OF MAN'S ENVIRONMENT

Robert N. Colwell

INTRODUCTION

The following is a report submitted to the Committee on Aeronautics and Space Sciences of the United States Senate in which many of the pertinent findings to date by research workers of the University of California, funded under the present grant, are summarized. The report was submitted to the Senate Committee at the request of the American Society of Photogrammetry.

The report begins with a tabulation of the unique combination of remote sensing capabilities to be found in ERTS-1. The value of this combination of capabilities is then considered in the light of five specific case studies which grant-funded University of California investigators have made, using ERTS-1 data.

The report concludes with the reproduction of a letter to Senator Moss which accompanied this report to him, dated August 1, 1974.

*ERTS" is now called "LANDSAT", but the term "ERTS" is retained here to agree with this material as already distributed and cited.

TABLE I
VALUABLE CHARACTERISTICS OF
ERTS DATA IN RELATION TO
THE INVENTORY AND MONITORING
OF EARTH RESOURCES

(NO OTHER VEHICLE PROVIDES THIS IMPORTANT COMBINATION OF
CHARACTERISTICS)

1. MULTISPECTRAL CAPABILITY
 - A. SENSES FOR THE OPTIMUM WAVELENGTH BANDS FOR USE IN THE INVENTORY AND MONITORING OF MOST TYPES OF EARTH RESOURCES (TIMBER, FORAGE, AGRICULTURAL CROPS, MINERALS, WATER, ATMOSPHERIC AND OCEANOGRAPHIC RESOURCES)
 - B. PROVIDES HIGH SPECTRAL FIDELITY WITHIN EACH OF THESE BANDS
2. MULTI-TEMPORAL CAPABILITY (PROVIDES MULTIPLE "LOOKS" FOR MONITORING SEASONAL CHANGES IN VEGETATION, RATE AND DIRECTION OF PLANT SUCCESSION AND THE ACCUMULATION OR RECEDING OF SNOW OR FLOOD WATERS)
3. CONSTANT REPETITIVE OBSERVATION POINT (FACILITATES CHANGE DETECTION BY MATCHING OF MULTI-TEMPORAL IMAGES)
4. SUN SYNCHRONOUS (NEARLY CONSTANT SUN ANGLE) ENSURES NEARLY UNIFORM LIGHTING AND UNIFORM IMAGE TONE OR COLOR CHARACTERISTICS FOR USE IN FEATURE IDENTIFICATION
5. NARROW ANGULAR FIELD OF SENSORS (570 MILE ALTITUDE AND ONLY 115 MILE SWATH WIDTH AVOIDS TONE OR COLOR "FALL OFF" AT EDGES OF SWATH AND THUS INCREASES STILL FURTHER THE UNIFORMITY OF IMAGE TONE OR COLOR CHARACTERISTICS)
6. PROVIDES COMPUTER-COMPATIBLE PRODUCTS DIRECTLY (FACILITATES AUTOMATIC DATA PROCESSING)
7. POTENTIAL MINIMUM DELAY IN DATA AVAILABILITY TO USER (PERMITS "REAL-TIME" ANALYSIS AND FACILITATES MAKING GLOBALLY UNIFORM RESOURCE INVENTORIES, WHEN APPROPRIATE, OR ANALYZING TROUBLED AREAS SUCH AS SAHEL, IN AFRICA)
8. SYSTEMATIC COVERAGE OF ENTIRE EARTH EXCEPT FOR NEAR-POLAR REGIONS
9. CAPABILITY FOR RECEIVING DATA FROM GROUND-BASED DATA PLATFORMS (FACILITATES USE OF "GROUND TRUTH" DATA IN THE INVENTORY AND MONITORING OF EARTH RESOURCES)
10. SPATIAL RESOLUTION IS OPTIMUM FOR "FIRST STAGE" LOOK AND IS POLITICALLY PALATABLE, BOTH DOMESTICALLY AND INTERNATIONALLY
11. DATA ROUTINELY PLACED IN PUBLIC DOMAIN FOR BENEFIT OF ALL MANKIND

TABLE II

SUMMARY TABLE SHOWING VALUABLE CHARACTERISTICS OF ERTS WHICH FACILITATE THE SUCCESSFUL COMPLETION OF CASE EXAMPLES I THROUGH V, AS DESCRIBED IN SUCCEEDING PAGES* ("X" INDICATES SIGNIFICANT VALUE FOR CASE EXAMPLE IN QUESTION)

CHARACTERISTICS OF ERTS**	CASE EXAMPLES (SEE TEXT)				
	I AGR	II FORESTRY	III RANGE	IV HYDROL	V HYDROL
1.	X	X	X		X
2.	X		X	X	X
3.	X		X	X	X
4.	X		X		X
5.	X	X	X		X
6.	X	X	X		X
7.	X		X		X
8.	X	X	X	X	X
9.			X		X
10.	X	X	X		X
11.		X	X	X	X

*TO COMPLETE THE ANALYSIS, SUB-SAMPLES OF DETAILED DATA INPUTS ARE NEEDED WHICH ARE ACQUIRED ON THE GROUND AND/OR FROM ULTRA-HIGH RESOLUTION AIRCRAFT OR SPACECRAFT IMAGERY

**FOR DESCRIPTION OF EACH ERTS CHARACTERISTIC SEE CORRESPONDING NUMBER IN TABLE I

CASE EXAMPLE NO. I

DISCIPLINE: AGRICULTURE

APPLICATION: CROP INVENTORY

INFORMATION REQUIREMENTS: ACREAGE OF MAJOR CROPS BY COUNTY AND IRRIGATION DISTRICT WITHIN LARGE AGRICULTURAL REGIONS. USER AGENCIES INCLUDE U.S. DEPARTMENT OF AGRICULTURE; STATE AGRICULTURAL AGENCIES; U.S. AGRICULTURAL STABILIZATION AND CONSERVATION SERVICE; CROP GROWERS ASSOCIATIONS; MANUFACTURERS OF AGRICULTURAL RELATED PRODUCTS; STATE AND COUNTY WATER RESOURCE DEPARTMENTS; AND LOCAL IRRIGATION DISTRICTS

STEP-WISE PROCEDURE:

- A. OBTAIN ERTS COVERAGE OF ENTIRE REGION ON REPETITIVE BASIS ON 3-5 SELECTED DATES DURING GROWING SEASON
- B. INTERPRETERS STRATIFY AREA INTO HOMOGENEOUS TYPES ON HARD COPY IMAGERY. COMPUTER PROCESSING (UNSUPERVISED CLASSIFICATION) OF DIGITAL DATA PROCEEDS IMMEDIATELY
- C. BASED ON INITIAL PROCESSING, FIELD VISITS ARE MADE WITHIN ONE WEEK
- D. USING GROUND DATA, SUPERVISED CLASSIFICATION BY STRATUM IS PERFORMED. AS SEASON PROGRESSES, MULTIDATE ANALYSIS IS USED IN ADDITION TO MULTIBAND ANALYSIS
- E. COMPUTER CLASSIFICATION IS CORRECTED AND ADJUSTED, USING GROUND DATA, AND SUMMARY STATISTICS ARE COMPILED

END PRODUCTS: SUMMARY STATISTICS OF CROP ACREAGES BY STRATA, COUNTY, REGION; ALSO MAPS OF CROP LOCATION IF NEEDED

CASE EXAMPLE NO. I (CONT'D)

IMPORTANT ERTS CHARACTERISTICS (SEE TABLE I): 1, 2, 3, 4, 5, 6, 7, 8, 10

COMMENTS: THE ABILITY OF ERTS TO PROVIDE COMPUTER-COMPATIBLE DATA WITH HIGH SPECTRAL RESOLUTION, AND THE ABILITY TO ACCURATELY OVERLAY MULTIDATE DATA AND TO OBTAIN A RAPID TURN-AROUND OF DATA TO THE USER ARE CRITICAL. INFORMATION IS INDISPENSIBLE TO RATIONAL PLANNING OF AGRICULTURAL POLICY, BOTH AT A NATIONAL AND INTERNATIONAL LEVEL, AND FOR FORECASTING MARKET CONDITIONS.

CASE EXAMPLE NO. II

DISCIPLINE: FORESTRY

APPLICATION: FOREST RESOURCES INVENTORY

INFORMATION REQUIREMENTS:

A. A STRATIFICATION BY TYPE (SPECIES COMPOSITION) AND/OR CONDITION CLASS (THE PHYSICAL STATE) AS FOLLOWS:

TRUE FIR	{ OVER MATURE, DECADENT POORLY STOCKED MATURE STANDS IMMATURE STANDS REGENERATION }	CONDITION CLASSES
MIXED CONIFER		
EAST SIDE PINE		
HARDWOODS		

NON FOREST-(CUTOVER), CROP, RANGE, BRUSH, WATER, ROADS, ETC.

NON COMMERCIAL-DERIVED FROM MANAGEMENT CONSTRAINTS:

WITHDRAWN (WILDERNESS, AREAS UNDER STUDY, ETC)

SENSITIVE AREAS

LOW SITE (PRODUCTIVITY) AREAS

CHRISTMAS TREE LANDS

B. AREAS AND BOUNDARY DELINEATIONS FOR EACH TYPE-CONDITION CLASS

C. YIELDS-VOLUME BY TYPE CONDITION CLASSES; QUALITY ASPECTS OF YIELD:
TREE CLASS, SIZE, DEFECT

D. GROWTH-COMPONENTS: SURVIVAL, MORTALITY, INGROWTH

E. PROGNOSIS-FUTURE YIELDS (DERIVED)

F. LAND USE CONSTRAINT CLASSIFICATION

I. NON-FOREST

II. FOREST

A. UNPRODUCTIVE (<20 CUBIC FT/YR GROWTH)

B. PRODUCTIVE (>20 CUBIC FT/YR GROWTH)

1. RESERVED (WILDERNESS, ETC.)

2. DEFERRED (PENDING CLASSIFICATION AS RESERVED)

3. COMMERCIAL

a. UNREGULATED (NOT SUITABLE OR DESIRABLE FOR SUSTAINED YIELDS, E.G., ADMINISTRATIVE, CHRISTMAS TREES, AND RECREATIONAL LANDS)

b. REGULATED

(1) STANDARD (INTENSIVE MANAGEMENT)

(2) SPECIAL (MANAGEMENT RESTRICTED BY OTHER VALUES)

(3) MARGINAL (CAPABLE BUT NOT CURRENTLY PRODUCING OR VALUED)

CASE EXAMPLE NO. II (CONT'D)

STEP-WISE PROCEDURE:

- A. HUMAN DELINEATION OF BROAD ENVIRONMENTAL STRATA USING HARD COPY PRODUCT
- B. DISCRIMINANT ANALYSIS OF DIGITAL TAPE DATA FOR TYPE AND CONDITIONAL CLASS
- C. SUB SAMPLING OF DISCRIMINANT ANALYSIS RESULTS PROPORTIONAL TO AREA OF TIMBER FOR VERY LARGE SCALE PHOTOGRAPHY TO OBTAIN SECOND STAGE ESTIMATES OF PARAMETERS
- D. SUB SAMPLING OF LARGE SCALE PHOTOGRAPHY FOR GROUND MEASUREMENTS OF INVENTORY PARAMETERS
- E. ERTS ESTIMATES ARE ADJUSTED TO REFLECT THE INFORMATION GAINED THROUGH THE SUBSAMPLING

END PRODUCTS:

- A. STATISTICAL SUMMARY OF EACH PARAMETER OF INTEREST
- B. MAPS OF PHYSICAL CONDITIONS OF THE AREA
- C. CONFIDENCE ESTIMATE FOR MAPPED AND STATISTICAL DATA
- D. COMPUTER DATA BASE FOR DIRECT USE IN RESOURCE ALLOCATION MODEL

IMPORTANT ERTS CHARACTERISTICS (SEE TABLE I): 1, 5, 6, 8, 10, 11

COMMENTS: THE APPLICATION OF THE ERTS DATA TO THE FORESTRY PROBLEM REQUIRES HUMAN AND COMPUTER PROCESSING OF BOTH HARD COPY IMAGERY AND DIGITAL TAPES. MULTIDATE, MULTISTAGE APPROACH WITH COMPUTER ANALYSIS OF THE DIGITAL DATA HAS PROVEN VERY COST EFFECTIVE. THE RESULTS OF THE ANALYSIS PROVIDE NEARLY ALL THE INFORMATION NECESSARY FOR THE MANAGER.

CASE EXAMPLE NO. III

DISCIPLINE: RANGE MANAGEMENT

APPLICATION: MONITORING CHANGES IN RANGE CONDITION

INFORMATION REQUIREMENTS:

- A. AVAILABILITY OF UTILIZABLE FORAGE
- B. CONDITION AND DEVELOPMENT OF FORAGE IN RELATION TO QUALITY AND QUANTITY OF FORAGE
- C. PHENOLOGICAL STAGE AT SPECIFIC TIME INTERVALS FOR COMPARISON OF CONDITION AND PRODUCTION BETWEEN AREAS WITHIN A REGION AND FOR COMPARISON OF CONDITION AND PRODUCTIVITY BETWEEN SEASONS FOR A PARTICULAR AREA.
- D. ASSESSMENT OF FINE-FUEL FLAMMABILITY
- E. ASSESSMENT OF AVAILABILITY OF SURFACE AND SOIL MOISTURE
- F. ASSESSMENT OF DROUGHT STRICKEN AREAS
- G. USER AGENCIES INCLUDE:
 - STATE CROP AND LIVESTOCK REPORTING AGENCIES;
 - FEEDLOT OWNERS AND CATTLE RANCHERS;
 - BUREAU OF LAND MANAGEMENT;
 - FEED SUPPLEMENT INDUSTRY; AND
 - STATE FIRE CONTROL AGENCIES

CASE EXAMPLE NO. III (CONT'D)

STEP-WISE PROCEDURE (OR APPROACH):

- A. UTILIZE MANUAL INTERPRETATION OF ERTS IMAGES, AND SPECTRAL DATA FROM ERTS TAPES COMBINED WITH SELECTIVE GROUND SAMPLING
- B. REQUIRES ANALYSIS OF SEQUENTIAL ERTS IMAGES ACQUIRED DURING INITIAL, AND MID-TO-LATE MATURATION STAGE OF PLANT DEVELOPMENT
- C. MULTIBAND/MULTIDATE ERTS IMAGES ARE REQUIRED TO RECONSTITUTE VISUAL COLOR IMAGES FOR DETERMINATION OF HEALTH, AVAILABILITY, AND DISTRIBUTION OF FORAGE VEGETATION
- D. SYSTEMATIC, REPETITIVE COVERAGE IS REQUIRED TO MONITOR CHANGES IN DEVELOPMENT OVER TIME
- E. TO BE OF MAXIMUM USE, SHORT TURN-AROUND TIME IS REQUIRED IN ORDER TO MAKE MANAGEMENT DECISIONS WHICH ARE RESPONSIVE TO CHANGES IN CONDITION OF FORAGE
- F. SPECTRAL FIDELITY OF ERTS IS ESSENTIAL TO COMPARE DIFFERENT AREAS WITHIN LARGE AREA SCENE AND ALSO IS REQUIRED FOR CALIBRATION PURPOSES WITHIN AND BETWEEN SCENES
- G. THE MULTI-SPECTRAL DATA FROM ERTS TAPES CAN BE EXTRACTED AND SPECTRAL REFLECTANCE RATIOS CALCULATED WHICH CORRELATE WITH CHANGES IN PHENOLOGICAL STAGE, FORAGE CONDITION AND AMOUNT OF GREEN BIOMASS
- H. GROUND SAMPLING IS REQUIRED TO ESTABLISH CORRELATION BETWEEN AMOUNT OF BIOMASS, PHENOLOGY, AND ERTS SPECTRAL REFLECTANCE RATIOS

IMPORTANT ERTS CHARACTERISTICS (SEE TABLE I): 1 THROUGH 11

END PRODUCTS:

- 1. A DETERMINATION OF THE TIME OF IMPORTANT PHENOLOGICAL EVENTS, E.G., SEED GERMINATION, PEAK FOLIAGE DEVELOPMENT, MATURATION
- 2. EVALUATION OF RATE OF CHANGE OF VEGETATION IN RELATION TO AVAILABLE MOISTURE
- 3. MAPS OF AREAL EXTENT OF AVAILABLE FORAGE BY FORAGE CONDITION CLASS, THROUGHOUT THE ENTIRE GRAZING REGION
- 4. QUANTITATIVE ASSESSMENT OF CHANGING PHENOLOGICAL STAGES
- 5. PERMANENT RECORD OF FORAGE CONDITION FOR COMPARISON WITH CONDITIONS IN SUBSEQUENT YEARS

DISCIPLINE: HYDROLOGY

APPLICATION: INVENTORY OF IRRIGATED LANDS

INFORMATION REQUIREMENTS: DETERMINE ACREAGE OF AGRICULTURAL LAND THAT IS UNDER IRRIGATION AT LEAST ONCE DURING THE COURSE OF EACH WATER YEAR. USER AGENCIES INCLUDE:

STATE AND COUNTY DEPARTMENT OF WATER RESOURCES ;
U.S. BUREAU OF RECLAMATION ; AND
LOCAL IRRIGATION DISTRICTS

STEP-WISE PROCEDURE:

- A. OBTAIN QUARTERLY ERTS COVERAGE OF ENTIRE STATE OR REGION (REQUIRES RAPID SYNOPTIC COVERAGE OF LARGE AREAS ON REPETITIVE BASIS)
- B. COLLECT GROUND DATA FOR SELECTED SAMPLE AREAS COINCIDENT WITH ERTS OVERPASS
- C. USING POINT SAMPLING APPROACH, INTERPRETERS ENUMERATE POINTS UNDER IRRIGATION ON EACH OF THE IMAGE DATES (REQUIRES CONSTANT GEOMETRY OF IMAGERY ON SUCCESSIVE PASSES AND SUCCESSIVE 18-DAY CYCLES TO ALLOW EASY LOCATION OF SAME SAMPLE POINTS ON THE IMAGERY ON EACH OF SEVERAL DATES)
- D. BASED ON POINT SAMPLE PERCENTAGES, ESTIMATE PERCENT OF TOTAL AREA BY COUNTY UNDER IRRIGATION, AND CONVERT PERCENTAGES TO ACREAGE ESTIMATES

END PRODUCTS: ACREAGE ESTIMATES OF IRRIGATED LANDS BY REGION, STATE, COUNTY, AND/OR IRRIGATION DISTRICT EACH YEAR

IMPORTANT ERTS CHARACTERISTICS (SEE TABLE 1): 2,3,8,11

COMMENTS: THE COMBINATION OF LARGE AREAL EXTENT OF SURVEY AREA, TRANSIENT NATURE OF THE PHENOMENON, AND NEED FOR REPETITIVE OBSERVATIONS MAKES THIS TASK PROHIBITIVELY EXPENSIVE USING CONVENTIONAL TECHNOLOGY. INFORMATION IS VERY IMPORTANT TO THE OPTIMUM PLANNING OF WATER DISTRIBUTION FACILITIES AND ALLOCATION STRATEGIES.

DISCIPLINE: HYDROLOGY

APPLICATION: SNOW SURVEY

INFORMATION REQUIREMENTS: PREDICTION OF WATER YIELD; SPECIFICALLY, THE ESTIMATION OF SNOW AREAL EXTENT, A FACTOR RELATED TO WATER YIELD. USER AGENCIES INCLUDE:

JOINT FEDERAL-STATE RIVER FORECAST CENTERS;
COOPERATIVE SNOW SURVEY ORGANIZATIONS;
MAJOR PUBLIC UTILITIES;
IRRIGATION AND WATER DISTRICTS;
CITY AND COUNTY AGENCIES

STEP-WISE PROCEDURE:

- A. USING A STANDARD MIRROR STEREOSCOPE, AN OBSERVER VIEWS TWO MULTIBAND COLOR ERTS-1 ENHANCEMENTS SIMULTANEOUSLY--ONE TAKEN DURING THE SUMMER SEASON SHOWING VEGETATION DENSITY AND TERRAIN CONDITIONS, AND ONE TAKEN DURING THE SNOW SEASON SHOWING SNOW CONDITIONS. MULTITEMPORAL ERTS-1 IMAGERY GIVES RELATIVELY FREQUENT VIEWS OF THE WATERSHED DURING SNOW ACCUMULATION AND MELT.
- B. THROUGH MINOR ADJUSTMENTS TO THE STEREOSCOPE AND IMAGE VIEWING HEIGHT, THE TWO IMAGES ARE BROUGHT INTO COMMON REGISTER, I.E., THE IMAGES AS SEEN BY THE ANALYST APPEAR TO BE SUPERIMPOSED ONE ON THE OTHER. (WITH ERTS, THE RELATIVE CONSTANT IMAGE CENTER LOCATION ALLOWS SUPERPOSITION OF IMAGES FROM DIFFERENT DATES.)
- C. A GRID OF KNOWN DIMENSIONS IS PLACED OVER THE SNOW SEASON IMAGE AND THE TOTAL PERCENT AREA WITHIN EACH GRID CELL THAT IS COVERED BY SNOW IS ESTIMATED AND RECORDED AS FALLING WITHIN A GIVEN PERCENTAGE COVER CLASS RANGE. ESTIMATION PROCEEDS ACCORDING TO AN ALTERNATE VIEWING OF SUPERIMPOSED IMAGES AND CONSEQUENT DECISIONS AS TO SNOW APPEARANCE BY COMPARISON WITH VEGETATION/TERRAIN TYPE KEYS, PREPARED IN ADVANCE. THE EXCELLENT SPECTRAL FIDELITY OF ERTS-1 IMAGERY ALLOWS UNIFORM INTERPRETATIONS TO BE MADE OF SNOW PRESENCE OVER THE ENTIRE AREA OF VIEW.
- D. AREAL EXTENT OF SNOW IS DETERMINED FOR ANY GIVEN WATERSHED FOR ANY GIVEN DATE BY CALCULATING THE TOTAL ACREAGE IN EACH SNOW COVER CLASS (NUMBER OF CELLS IN EACH CLASS X AVERAGE NUMBER OF ACRES PER CELL), AND MULTIPLYING THE ACREAGE VALUE IN EACH CLASS BY THE PERCENTAGE MIDPOINT OF THE RESPECTIVE CLASS. IF DESIRED, THE OVERALL NEW ACREAGE ESTIMATE MAY THEN BE CALIBRATED BY USE OF AN INEXPENSIVE SAMPLE OF LARGE SCALE PHOTOGRAPHS OF BASIN SNOW CONDITIONS FOR THAT ERTS-1 SNOW DATE WITHIN THE WATERSHED OF INTEREST.

END PRODUCTS: ACREAGE ESTIMATES OF AREAL EXTENT OF SNOW BY WATERSHED, OR MANAGEMENT UNIT DURING THE PERIODS OF PEAK ACCUMULATION AND MELTING, WHICH MAY THEN BE USED AS ONE VARIABLE IN WATER YIELD PREDICTION EQUATIONS.

IMPORTANT ERTS CHARACTERISTICS (SEE TABLE I): 1 THROUGH 11

COMMENTS: THE DIRECT TELEMETERING OF ERTS-1 DATA TO THE GROUND IS VITAL FOR TIMELY, INEXPENSIVE DETERMINATION OF SNOW AREAL EXTENT OVER MANY LARGE WATERSHEDS. THE RELATIVELY LOW SPATIAL RESOLUTION OF ERTS-1 DATA ALLOWS ACCURATE ESTIMATES OF SNOW COVER TO BE MADE WITHOUT UNDULY HIGH AND THUS EXPENSIVE DATA LOADS. LASTLY, THE EXPERIENCE FACTOR GENERATED BY PERIODIC, UNIFORM, ADEQUATELY RESOLVED VIEWS FROM ERTS-1, MAY ALLOW CHARACTERIZATION OF THE AVERAGE SNOW EXTENT DYNAMICS RESULTING IN MORE COST-EFFECTIVE SAMPLING PROCEDURES.



SPACE SCIENCES LABORATORY

BERKELEY, CALIFORNIA 94720

APPENDIX I TO SPECIAL STUDY NO. 2

August 2, 1974

The Honorable Senator F. E. Moss
United States Senate
Committee on Aeronautics and Space Sciences
231 Russell Senate Office Building
Washington, D.C. 20510

Dear Senator Moss:

The American Society of Photogrammetry, which is this country's leading professional (non-profit) society concerned with achieving the intelligent use of aerial photography, space photography and other forms of remote sensing data, has asked me to convey to your committee my evaluation of Earth Resources Technology Satellites, such as ERTS-1, in terms of their potential benefit to mankind. Presumably I have been asked to respond because (1) For more than 30 years I have been making inventories from conventional aerial photos of various earth resources (timber, forage, soils, water, minerals, agricultural crops, etc.); (2) For the past several years I have been making similar inventories both of an operational nature and of a research nature with the aid of space photography in my capacity as Professor of Forestry and Associate Director of the Space Sciences Laboratory of the University of California and also as Director of the Berkeley Office of a private industrial concern known as Earth Satellite Corporation; and (3) As an honorary life member of the American Society of Photogrammetry and frequent office holder within that organization, I am among those who are often called upon to comment on matters, such as this, which are of primary concern to that Society.

At the outset I should emphasize that the two-fold objective of virtually all the work I have been engaged in has been (a) better management of the various earth resources for which inventories were being made, and (b) better preservation of the environmental complex associated with those resources. Hence, my comments will pertain primarily to the usefulness of ERTS-type data in relation to these objectives. As your committee members well know, the achieving of these objectives is a matter of increased concern to mankind because of his increased awareness in recent years of two related facts:

- (1) the human demand for most kinds of earth resources, whether on a local, national or global level, is rapidly increasing, due to both the increased population and the increased per capita demand for these resources, and
- (2) the supply of some of the most important of these resources is rapidly dwindling and the quality of certain others is rapidly deteriorating.

In January, 1972, at a joint meeting of the Committee on Science and Astronautics of the U.S. House of Representatives and its associated Panel on Science and Technology, I presented a paper which still serves as an adequate statement of my views on most of the points about which I have now been asked to comment. That paper was entitled "The Future for Remote Sensing of Agricultural, Forest and Range Resources." It included major sections dealing with such topics as (1) Potential Users of Remote Sensing Data and their Informational Requirements, (2) Who Needs Information on Crop Losses and Why?, (3) Future Prospects for the Use of Remote Sensing in the Management of Renewable Natural Resources, and (4) Some Factors to be Considered in Developing Operational Plans for the Remote Sensing of Renewable Natural Resources. Since you, of course, have access to that document, I will simply invite your attention to the fact that it dwells at length on the benefits to be achieved through the making of better resource inventories within the continental limits of the United States and then directs attention to the potential benefits derivable from global resource inventories. In this latter regard I should like to repeat here the quotes which were included in my paper from a speech given by the President of the United States to the United Nations General Assembly on September 18, 1969 and entitled "Toward an Open World":

...We are just beginning to comprehend the benefits that space technology can yield here on earth, and the potential is enormous. For example, we now are developing earth resource survey satellites, with the first experimental satellite to be launched sometime in the decade of the seventies. Present indications are that these satellites should be capable of yielding data which could assist in as widely varied tasks as these: the location of schools of fish in the oceans, the location of mineral deposits on land, and the health of agricultural crops. I feel it is only right that we should share both the adventures and the benefits of space. As an example of our plans, we have determined to take actions with regard to earth resource satellites as this program proceeds and fulfills its promise. The purpose of those actions is that this program will be dedicated to produce information not only for the United States but also for the world community...[such an adventure] belongs not to one nation but to all mankind and should be marked not by rivalry but by the same spirit of fraternal cooperation that has long been the hallmark of the international community of science.

Elsewhere in his presentation, the President asserted that within the next decade, "We can make significant gains in food production," spoke of "the urgent need for international cooperation in spurring economic development," and pointed out the need for "a fuller enlistment not only of government resources and private enterprise resources but also of the dedication

The Honorable Senator F. E. Moss
August 2, 1974
Page 3

and skills of those thousands of people all over the world who are ready to volunteer in human achievement."

Consistent with the thoughts quoted above, the work done to date by various agencies and individuals has demonstrated that ERTS-1 data properly analyzed often can facilitate the making of regional, national or even global resource inventories of certain kinds of earth resources, thereby facilitating resource management and environmental protection.

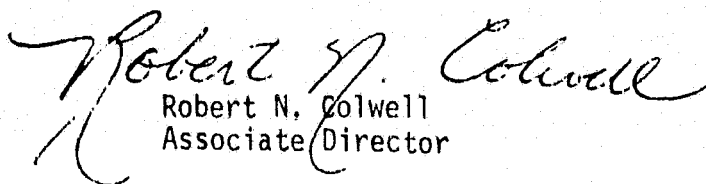
The President's comments notwithstanding, many authorities in this country consider that ERTS should be evaluated primarily in terms of its domestic benefits, i.e., its usefulness directly within the United States. Hence, in the accompanying short document I have attempted to report, first, on a few of the experiences we have had to date within the United States relative to the usefulness of ERTS-type imagery. Thereafter, the report briefly considers examples of information obtainable (by means of ERTS data) in other parts of the globe. The examples chosen are considered to be representative ones in that they are of concern to the United States for humanitarian reasons and/or because the United States, like many other nations, is becoming increasingly dependent upon earth resources beyond those produced within their national boundaries. It follows that global inventories, if sufficiently timely and accurate, can do much to alleviate local imbalances between the production and consumption of earth resources with consequent benefit to people throughout the United States and the rest of the world.

The report which I am submitting as an enclosure to this letter reflects the rationale expressed in the foregoing paragraphs. As previously indicated, it draws heavily on findings which my colleagues and I have arrived at.

It will be apparent from a reading of this report that I am among those within the American Society of Photogrammetry who hold the following firm beliefs: (1) this country should continue, without interruption, to build upon the very substantial progress which it has made in recent years toward the development of an operational satellite for use in the making of earth resource inventories, and (2) such progress can only be ensured through the early launching of ERTS-B and authority to proceed with ERTS-C.

If your committee desires additional information from me I shall be most happy to provide it.

Respectfully yours,


Robert N. Colwell
Associate Director

SPECIAL STUDY NO. 3

STATEMENT BEFORE THE
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS
OF THE
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
U.S. HOUSE OF REPRESENTATIVES

NINETY-THIRD CONGRESS

SECOND SESSION

by

Robert N. Colwell
Associate Director, Space Sciences Laboratory
University of California

Mr. Chairman and Members of the Subcommittee:

It is both a pleasure and an honor to appear before this Committee to present my views on the present status and potential future usefulness of earth resources survey programs in general and of earth resources technology satellites in particular.

At the outset and in the interest of avoiding redundancy, I must mention two previous statements of mine which overlap somewhat the one which I have been asked to give today. The first of these (Colwell, 1972a) was presented before your Committee nearly 3 years ago and dealt with the future for remote sensing of agricultural, forest and range resources. That presentation was given on the eve of what I referred to as "the most important photographic experiment in history," - - the one which would begin with the launching of the world's first Earth Resources Technology Satellite,* ERTS-A.

The second of these earlier statements of mine (American Society of Photogrammetry, 1974) was presented only a short time ago to the Senate Committee on Aeronautical and Space Sciences. Since my second statement was prepared after ERTS-A (ERTS-1) had been in operation for a full two years, it provided me with an opportunity to summarize briefly how things had been going in that highly heralded experiment.

My basically optimistic evaluation, as given on that second occasion, was in marked contrast to the following pessimistic evaluations quoted to that same Committee by a distinguished representative of the Office of Management and Budget (Zarb, 1974).

1. The Statistical Reporting Service of the Department of Agriculture has asserted that "without significantly improved resolution and dependability there is no possible way the ERTS system can achieve any improvements over the existing crop

* "ERTS" is now called "LANDSAT", but the term "ERTS" is retained here to agree with this material as already distributed and cited.

forecasting system"

2. The Forest Service has stated that "there is as yet no demonstrable need in forest inventory, the major area of benefit in forestry, for frequent acquisition of the relatively low resolution produced by ERTS" and
3. The Environmental Protection Agency, in commenting on ERTS, has similarly stated that "while some benefit may be derived from the examination of low resolution imagery, the great bulk of the essential elements of information required to produce a piece of finished environmental information lies well below 30 feet resolution" (as compared with the 10-fold poorer resolution, approximately, that is provided by ERTS).

Comments such as these prompted Dr. Zarb to testify with a fourth, and summarizing statement, as follows:

4. "the present ERTS technology is not yet good enough to justify a commitment to an operational system". Pointing to the need "to achieve significantly better resolution" he concluded that "any additional launch, beyond ERTS-B, of a remote sensing satellite should be carried out only when such a launch can be shown to be the most cost-effective way to achieve a significant advance in the state of the art".

There is a remarkably good consensus among the 4 viewpoints which I have just quoted. Furthermore they come from some of the most authoritative offices in this country. Therefore, there would seem to be no justification for me to occupy the time of your busy committee if it were merely so that you could hear additional testimony that was basically in agreement with these assertions. Such is not the case, however. Therefore, I will now proceed to indicate why I disagree with them. However, I will do so not because of any inherent belligerence that causes me to enjoy disagreeing with the experts, even to the point of questioning whether they know how to run their own business. Having worked closely for many years with such officials from the agencies quoted, I have great admiration and respect for their abilities, despite a few honest disagreements. Instead the rationale for my perilous course of action is simply as follows: your Committee obviously needs to know whether there are any valid challenges to the 4 assertions which I have just quoted as it seeks to decide whether it should favor the commitment of this country to the launching of ERTS-C in the near future and thus to the sustaining of a long-term and continuous ERTS-type of operational remote sensing system.

1. Can ERTS-Type Data Help Improve Crop Forecasting Systems?

Crop forecasting systems that presently are in use are able to acquire quite accurate information periodically on crop type and probable crop yield in selected sample areas or "segments". Two possibilities for sizable errors exist, however, under these systems: (1) The selected sample areas

may not be adequately representative of the entire area to which such sample data are applied, and (2) The total agricultural acreage (a factor which is of great importance in developing "expansion factors" for the sample data) may not be known with sufficient accuracy.

If a crop forecasting system were to be based on ERTS derived data, the fact that the entire agricultural area could be viewed would reduce the potential for errors due either to unrepresentative sampling or to uncertainty as to the total agricultural acreage. Two possibilities for sizable errors would exist, however, if only the ERTS-system were to be used:

- (1) those due to the misidentification of crop types, and
- (2) those due to inaccurate forecasts of crop yields.

Experience with ERTS in California and elsewhere has shown that the multirate coverage of agricultural areas which it provides (at 18-day intervals, weather permitting, throughout the growing season) permits one to identify the more important crops in many instances to an accuracy of greater than 90 per cent. Furthermore there is reason to believe that two factors could greatly improve the accuracy with which crop yields, field-by-field, could be forecasted from ERTS-data.

(1) The use of pertinent data readily available from meteorological satellites, on temperature, precipitation and light intensity conditions existing in various parts of the agricultural area and at various critical times during the crop growing season and (2) the compilation, over a period of several years, of aids to crop yield estimation known as "photo interpretation keys". The value of such keys for similarly difficult photo interpretation problems already has been demonstrated on numerous occasions. In this instance the keys would consist of two components: (a) ERTS image examples of fields that had been monitored on the ground so that both crop type and crop yield were accurately known, field-by-field, and (b) word descriptions which would set forth in concise terms the photo image characteristics which were of greatest diagnostic value both for the identification of crop types and the forecasting of crop yields.

In summary of this section, 3 points seem worthy of emphasis: (1) It is quite unlikely that a crop forecasting system based entirely on ERTS data would ever provide sufficient accuracy to satisfy the needs of those using such forecasts; (2) Even at the present time, however, ERTS could be of great value as a supplement to the on-the-ground crop forecaster by permitting him better to select representative "segments" and better to determine the expansion factors to which data collected from such segments should be applied. (It is at this point that I find myself in substantial disagreement with the previously quoted statement that "there is no possible way that the (present) ERTS system can achieve any improvements over the existing crop forecasting system", and (3) If we were to be given a continuous period of several years during which to develop photo interpretation keys and to derive empirical relationships between crop yield and the data provided by both ERTS and meteorological satellites, we would make great progress, indeed, toward improving

present crop forecasting methods. With the ever-increasing demand for food and fiber and the ever-dwindling amount of arable land, the importance of developing such a capability in order to help ensure adequate crop production (whether regionally, nationally or globally) can scarcely be overemphasized.

2. Can ERTS-Type Data Help Improve Forest Inventories?

Forest inventory techniques that presently are employed make effective use of aerial photographs, but rarely do they make use of space photography such as that which ERTS can provide. Some of the most knowledgeable experts in the field of forest inventory have stated that a system, such as ERTS, which cannot resolve individual trees offers nothing of value to them. Others soften this viewpoint by asserting that the frequent acquisition of such imagery is not as yet a demonstrable need.

Although the second of these assertions is significantly different than the first, and although even the first does not address itself to all potential forestry uses, the net impact on many decision makers appears to be essentially the same, viz. that, at least from the forestry stand point, "present ERTS technology is not good enough to justify a commitment to an operational system".

My colleagues and I at the University of California have been conducting studies during the past year to determine the potential usefulness of ERTS-1 data as an aid to the making of timber inventories. Our test area has been a representative portion of the mixed conifer forest of California's Sierra Nevada Mountains. In this work we have maintained close contact with local personnel of the U.S. forest and with numerous representatives of the forest industry the better to ensure that our research would be truly meaningful.

In one such test we investigated the usefulness of ERTS-1 data as an aid to determining timber volume only since this is perhaps the simplest kind of forest inventory worthy of testing. A basic premise in this study was that timber stand density (i.e. the proportion of the ground that is obscured by trees when the forest is viewed from overhead, as on ERTS-1 imagery) is a very useful, though admittedly rough indicator of timber volume. Based on this criterion a rough timber-volume classification was made from the ERTS-1 data of every resolution cell. Since each such cell is slightly greater than 200 feet on a side the result was essentially an acre-by-acre classification).

Using sampling techniques based on probability in proportion to volume (ppv), sites were selected within which to obtain large scale aerial Ekta-chrome photography through use of a 35mm camera mounted in a light aircraft. On this photography tree heights and crown diameters were measured thereby providing much more refined estimates of timber volumes.

From the results thus obtained, and again using "p.p.v." sampling techniques, still smaller subsamples were selected. Ground survey crews visited these few sites and accurately measured the volume of each merchantable tree with the aid of an optical dendrometer.

Once this three-stage ERTS-based sampling scheme had been completed, the proper expansion factors were developed and applied, thereby providing a timber volume estimate for each portion of the test area and for the property as a whole.

Results of this test indicated that an acceptable order of accuracy could be achieved more quickly and at less than half the cost through use of the ERTS-based method as compared with conventional methods for timber volume assessments.

While some skeptics might raise the question of whether a "random success" was achieved in this instance, Forest Service personnel at both the local and national level are far more appreciative than they previously were of the value of ERTS-type data as an aid to forest inventory.

In most parts of the United States a timber inventory deals not merely with the estimation of timber volumes, but also with an appraisal of timber stand conditions and growth rates. Consequently our group has been conducting additional tests along these lines and appears to be achieving similar success, although final results will not be available until about 2 months from now.

Still another sense in which the term "forest inventory" is used by some is with respect to the entire "resource complex" of a forested area, including the timber, forage, soils, water minerals, fish, wildlife and recreational potential. Under sponsorship of the Bureau of Land Management our group is nearing completion of such an inventory for a 2-million acre area in north-eastern California. Based on results achieved to date there is little doubt among either the investigators or their sponsors that the most cost-effective way currently available for making such a survey involves the use of ERTS-type data as the first stage in a multistage sampling scheme.

3. Can ERTS-Type Data Help Improve Environmental Analyses?

As previously indicated the Environmental Protection Agency considers that ERTS-type data can be of only limited interest because of the limited spatial resolution which it provides. This may be true as applied to the making of traditional "environmental impact" studies of local areas and especially when the concern is primarily with respect to the immediate or short-term environmental effects. However, there is increasing evidence that environmental concerns and in consequence that environmental analyses should be macroscopic as well as microscopic (even to the point of providing broad regional or even global analyses) and that these concerns should also consider long term as well as short term environmental impacts. To the extent that these broader considerations become important, so does the potential usefulness of ERTS-type data. A century ago man's appreciation of his environment was essentially limited to what he could acquire while observing it from the ground,--a vantage point which offered him little better than the "worm's eye view". With the advent of the aircraft he was provided with the "bird's-eye" view that greatly broadened his environmental perspective. And since the dawning of the space age he has been provided with what some enthusiasts refer to as the "God's eye view". I hasten to

state that it does not follow that man is thus able to acquire God's full perspective of what is happening to the earth's environment. There are numerous instances, however, in which the broad perspective and limited resolution of space-acquired ERTS-type data can elucidate environmental relationships that man previously was unable to discern. This is true not only because of the more limited perspective of earlier systems, based on aerial photography but also because the resolution of such systems provided such a large amount of detail that he couldn't appreciate the true nature of a forest (for example) because of the high-resolution noise from the individual trees.

And as for the short time-span that often is used as the frame-of-reference of the environmentalist as he makes detailed environmental impact studies, it often is too short, I believe, and certainly too short to achieve maximum benefit from ERTS-data. In this regard, it is my flat prediction that the greatest value of all of the data acquired to date by ERTS-1 will emerge some 50 to 100 years from now when environmentalists of that day can go back to the first adequately detailed look that man ever obtained of this globe, viz. the look that was obtained and faithfully recorded by ERTS-1 in the early 1970's -- shortly before man irreversibly ruined major portions of it. By thus discerning clearly what environmental tragedies occurred on a grand scale, and thus by better understanding why they occurred, man hopefully will then be able to learn in the nick of time how to avert similar environmental tragedies in such parts of the globe as he has not by then got around to ruining.

4. Is Present ERTS Technology Good Enough to Justify Commitment to an Operational System Now?

Dr. Zarb seemingly answered this question with great finality when he said, "Any additional launch, beyond ERTS-B, of a remote sensing satellite should be carried out only when such a launch can be shown to be the most cost effective. . ."

The time when that will come seems to be related more to the development of faith than technology. The faith to which I refer is one that needs to be developed between budgetary officials and the potential users of ERTS data.

On the one hand, it appears that even now budgetary officials would approve the timely launch of ERTS-C if they had faith that enough potential users of its data would, indeed, do so.

On the other hand, it appears that a major deterrent to the receiving of such declarations from potential users is their lack of faith that budgetary officials will appropriate the funds required to insure the availability of ERTS data on a continuing basis.

For example, many of the resource managers with whom my associates and I work, (particularly those who seek to manage such renewable natural resources as agricultural crops, timber, forage and water) and also many of the environmentalists with whom we work, are convinced that ERTS technology.

already is good enough to justify abandonment of their old data basis and their switching to new ones which would use ERTS as the primary initial data input. They have no intention of making such a dramatic, and perhaps traumatic switch, however, until they have more faith than at present in the continuing availability of ERTS data. Because of the dynamic nature of these renewable natural resources, any system designed for use in monitoring them must provide updating information at suitably frequent intervals. The ERTS system has that capability, but obviously if ERTS vehicles do not continue to fly the required capability is lost. Quite understandably faith in the continuity of such a system is difficult for the potential users of ERTS data to develop under present circumstances. This is especially true when those officials who would need to authorize the funds for such a continuing effort make assertions such as the one which I previously quoted, VIZ. that "the present ERTS technology is not good enough to justify an operational system."

In the presence of this dilemma it is perhaps essential that I cite one or two specific instances in which potential users of ERTS data are, even now, on the threshold of switching to an information system which would make cost-effective use of ERTS data. In so doing I will continue to confine myself primarily to potential users and uses of ERTS data in the geographic area with which I am most familiar, VIZ. the state of California.

A. Preplanning in Relation to the Suppression of Fires in Wildland Areas

More than half of California's 100 million acres is classified as "wildland". Much of this vast area contains either highly flammable brush and herbaceous vegetation or highly valuable timber. Furthermore, these vegetation types in many instances clothe steep and highly erodible slopes and often they are intermingled with expensive summer homes and recreational developments.

Because of this combination of circumstances, several federal agencies including the U.S. Forest Service, the Bureau of Land Management and even the Department of Housing and Urban Development have expressed great interest in minimizing the damage inflicted in these areas by wildland fires.

One step that has long been recognized as an aid in reducing these losses is known as "Pre-planning" by means of which a strategy is developed in advance for use in combatting wildland fires wherever they may develop. The effectiveness of this strategy is greatly improved if a detailed knowledge of fuel types, area-by-area, is available. Preliminary research results obtained by my research group working in concert with the interested agencies, have demonstrated the value of ERTS data as the basis for mapping fuel types to uniform standards throughout California. From such information fire-fighting officials and agencies can intelligently engage in various pre-suppression activities, including the locating and

building of fuel-breaks, helicopter landing sites and water storage tanks.

The value of this information would be enhanced if, in addition, accurate and current information were to be available at all times relative to fuel flammability and fire danger ratings, area-by-area, throughout this vast acreage. There is reason to believe that the thermal infrared scanner proposed for inclusion on ERTS-C, together with timely information provided at frequent intervals by meteorological satellites, would do much to provide this additional information.

B. Post-Burn Damage Assessment and the Planning of Rehabilitation Measures.

Large sums currently are expended each year in California in attempting promptly to rehabilitate wildland areas following burning.

Fire officials within the California Division of Forestry are among those who have developed a healthy respect for ERTS data as a means to that end. For example, less than 72 hours after ERTS had been launched it photographed a recently burned area in California with sufficient clarity to permit ERTS data analysts to estimate its areal extent 25 per cent more accurately than was done by conventional aerial and ground surveillance techniques. Such an increase in informational accuracy is of interest to many groups including those who must pay their pro-rated share (on an acreage burned basis) of the fire suppression costs and those who must develop a prompt and effective post-burn rehabilitation program.

In my oral presentation of this paper I will cite other examples with the aid of lantern slides. Those examples will serve to emphasize the essentiality of our having a continuity of ERTS-type data over a period of several years, the better to develop empirical correlations between ERTS data and ground truth and the better to determine the amount of year-to-year variability that can be expected with respect to this nation's renewable natural resources. It will be obvious from my discussion of those examples that I strongly favor a commitment being made now to an ERTS-type of operational system and, axiomatically, to the launch of ERTS-C at the propitious time for ensuring a continuity of ERTS data.

I would say finally -- we can have the lights on as I conclude -- that several of the groups that we work with, i.e., the user agencies, indicate that they would be prepared to use ERTS type data right now, except for the following dilemma: On the one hand they are reluctant to switch away from their present resources inventory techniques, until they can be assured that, having gone through this traumatic experience, they will have a continuum of ERTS imagery in the future. On the other hand we have the other half of the dilemma in which OMB in effect says, "We don't want to Okay this continuum until we hear these people saying that they are ready to use ERTS data cost effectively now." So in contrast to the statement which Doctor Zarb made to the effect that we can't go further with this ERTS program until it has been proven cost effective, and until the ERTS technology has improved, it seems to me that it is not so much a question of technology, even at the

present moment, as it is a matter of mutual faith among these two groups. And, if I were to point out the single key item that would rectify that difficulty, it would be some kind of assurance from OMB, certainly beyond what we have at the present time, that there would be a continuity of ERTS type data, at least for several years, as would be assured with the launching of ERTS-C, for example. These resource managers and user agencies would then feel that it would be cost effective to start switching to these techniques now.

Thank you very much.

Mr. Symington. Doctor Colwell, thank you for your as usual splendid, if not spectacular statement of the case.

I don't know whether you were here during the statement by OMB's representative?

Dr. Colwell. I heard the last half of one of their statements.

Mr. Symington. Of course you had obviously read it, because you prepared your presentation with it in mind. I think that has proven very helpful to the Committee.

Of course, the date and the context of the statements that you quoted are crucial. Those attitudes could well be modified by now. We have had a presentation today by General Electric on the digital analysis of crop forecasting and things of that sort, which I think none of us has seen and I doubt that OMB's witness had seen yet. It is a thing that happens almost daily.

Doctor Colwell. In this regard might I cite an analogy which is credited to one of my associates, Doctor Levin. Although perhaps it was not part of his testimony to Senator Moss' Committee, Ben Levin gave me a couple of days ago the following analogy which I think is well worth considering. "At the present time we are asked to evaluate the usefulness of ERTS, much as though we had been asked, through detailed anthropomorphic measurements of a 7-year-old child, to estimate whether this child will become a great heavyweight boxer. We just can't make an accurate estimate from measurements made that early in the child's development." I would submit then, with reference to the comments you have just made, Mr. Symington, that even in the interim during which the potential of ERTS has been debated in the last few months, researchers have progressed to where we are now, (to use the same analogy), able to measure a teenager instead of a seven-year-old and we are about to say "yes," this will be a good heavyweight boxer, something we would not have not been able to say with any certainty a few months or a few years ago. I think it is a very useful analogy.

Mr. Symington. I wonder if you would accept an appointment as Director of the OMB as soon as we can arrange it.

Doctor Colwell. I am distressed by the fact that people of OMB who

need to see images as well as hear words missed my lantern slide presentation today. Without the slides, my paper is just some more words. I can hardly talk about the real capability of ERTS, however, without getting tears in my eyes. I wish OMB could get that kind of tears once in a while by seeing this kind of testimony.

Mr. Symington. They have sort of a fog which takes the place of tears.

Mr. Bergland?

Mr. Bergland. Mr. Chairman, I want to congratulate Doctor Colwell for his very splendid presentation and I am curious to know, Doctor, have representatives of OMB seen your work?

Doctor Colwell. I am fairly sure they have not. California is pretty far west compared to Missouri and some of these other places from which reports on the usefulness of ERTS have been submitted.

Mr. Bergland. They have not had the benefit of first hand exposure to the kind of thing that you are doing and the enormous potential that many of us see within your efforts?

Doctor Colwell. Well, I think they have not seen or heard my particular report. However, I am highly respectful of the very valuable research done, primarily under NASA funding, by a whole host of groups, so while I wish they could have seen this presentation, if they have not yet been convinced, I am among those that are inclined to despair that they ever will be. If OMB rejects ERTS-C on the grounds that presents ERTS resolution is no good, and that ERTS-I must be proven cost-effective before OMB can approve ERTS-C, then I consider them wrong on both counts and these are essentially the arguments which I am rebutting here. But everyone else that has worked with this imagery instead of merely philosophizing about it arrives at essentially the same conclusions as I do. I doubt that OMB is going to do a 180° turnabout just because I get up and show my slides and do a little arm waving. I would welcome a chance of trying to persuade them, but I think it would be discourteous to my fellow researchers across the country if I implied that there is something so unique about my aspect of ERTS research that therefore OMB has to hear my story.

Mr. Symington. You project rather well. You are very persuasive, Doctor.

Doctor Colwell. Thank you, sir.

Mr. Symington. Thank you.

Your statement, Doctor Colwell, will be made a part of the record, the written statement as well as, of course, your verbal one.

I wish that the OMB representatives or at least one of them might have stayed behind. I don't think any did. At least, nobody is holding up their hand to that effect. So, we will just try in some fashion to bring them to an awareness of the approach you have taken and ask them for their comments.

I think without the sort of integrity and fire such as yours, we wouldn't be able to get this Committee to move the Congress in the direction I think we ought to go, or the country. So we are extremely grateful to you for visiting with us again today. We hope we can count on you in the future.

(Whereupon, the prepared written and oral statements of Doctor Colwell were entered into the record.)

Doctor Colwell. Yes Sir. Finally my apologies for the in-and-out appearance I had to make here. It happened that this is a pretty busy day for me. I am pleased that you adapted yourself to this schedule. Thank you sir.

Mr. Symington. Very happy to do so. Thank you very much.

The Subcommittee will meet again tomorrow at ten o'clock in this room.

Today we are adjourned.

(Whereupon, the Subcommittee adjourned at 12 o'clock noon, to reconvene on Friday, October 4, 1974 at 10:00 a.m.)

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SPECIAL STUDY NO. 4

INPUT QUALITY ENCODING OF MULTISPECTRAL DATA*

V. Ralph Algazi

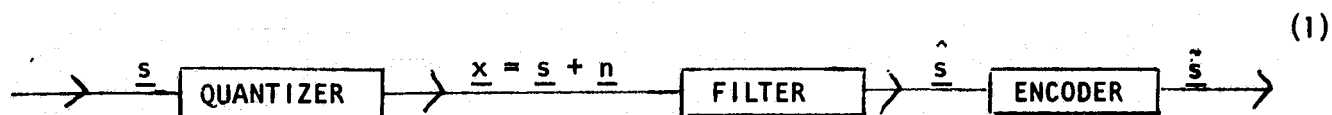
Presented at the 1974 Picture Coding Symposium,
August 1974, Goslar, West Germany

1. INTRODUCTION AND OBJECTIVES

In the efficient representation and encoding of data, the engineer will generally exploit the statistical redundancy present in the data and try to accommodate the fidelity requirements specified by the user. In the case of multispectral data, in which many users are involved, it is difficult to specify a data quality which will accommodate all users. For error free analog data it is well known that an infinite bit rate is needed to represent the data exactly. Assuming digitized data, Spencer and May [1] have examined error free encoding techniques which use differential encoders. However, a more general statement as to the quality acceptable in the encoding of multispectral data is that encoding should preserve data quality as determined by image sensors and input quantization. Thus we can use data correlation for quantization noise reduction as well as for encoding with some errors, as long as the total error in the digital data is not larger than the total error in the original data. We have used linear transformation techniques and some theoretical results of others and ours to study this problem [2,3,4].

2. THEORETICAL BASIS

The steps in the optimum encoding of noise source are shown below:



In the mean-square sense the optimum filter is followed by the optimum encoder

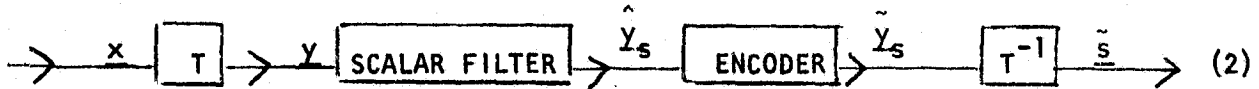
D_{est} = Residual estimation M.S. error

D_{cod} = Encoding M.S. error

then the encoding preserves the input quality of the data.

* Work supported in part by NSF Grant GK-37282

In filtering and encoding use Karhunen-Loeve transformation for optimum results for finite block size. Recursive techniques can be used in encoding and/or filtering in suboptimum schemes. When using transforms we schematically have the following



in which T is the Karhunen-Loeve or a fast unitary linear transformation.

3. THEORETICAL RESULTS BASED ON ACTUAL DATA

In the theoretical analysis of this approach to encoding we have assumed the following models:

a. Quantization Error: $\sigma_n^2 = \frac{Q^2}{12}$, σ_n^2 quantization error variance we

assume L quantization levels, $Q = \frac{6\sigma_s}{L} = \frac{6\sigma_s}{2^b}$, in which there are b bits

quantizer between $\pm 3\sigma_s$.

b. Image Statistics: Gaussian, zero mean

Spatial: Separable first order Markov

$$E[s_{ij}s_{kl}] = e^{-\alpha[|i-k| + |j-l|]}$$

$$.05 \leq \alpha \leq .15$$

which fit ERTS-1 data quite well.

Spectral: We use ERTS-1 multispectral scanner statistics. We verified that spectral-spatial statistics are separable.

We have examined the results achievable using most of the transforms of interest: Karhunen-Loeve (KL), Discrete cosine (DC), Fourier (FR), Hadamard (HD), Haar (HA), slant Hadamard (SLD), Slant Haar (5) (SLHA), and the effects of encoding one dimension, two dimension spatially, on a spectral-spatial encoder.

We illustrate the results obtained by two graphs. In Figure 1, we show the number of bits needed to represent the data, assuming the number of quantization levels shown in abscissa. The encoder uses a $4 \times 4 \times 4$ block of data. We note that most fast transforms perform as well as the optimum Karhunen-Loeve.

In Figure 2, we illustrate the effect of data statistics, in particular, of the spatial correlation of the data. We note that a theoretical rate of 2 bits per pel is possible with data degradation, starting from 6 bit quantized data.

4. EXAMPLE OF IMPLEMENTATION

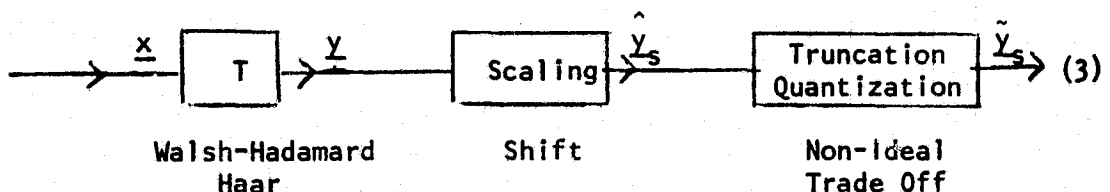
We used ERTS-1 data from Northern California

a. Noise Model: The small variances of the 3 dimension covariance matrix measures error variance. This is needed because we have to account for sensor noise as well as quantization noise.

b. Block Size: From theoretical results, a $4 \times 4 \times 4$ block represents a compromise between performance and speed.

c. Local Means: on 4×4 blocks for each spectral bands are removed.

d. Block Diagram: A block diagram of the implement algorithm is shown below



IMPLEMENTATION WITHOUT MULTIPLICATION

e. Typical Result:

Errors: We can only measure the error between reconstructed and input data and thus

$$E[|\tilde{s} - x|^2] = E[|\tilde{s}|^2] + E[|n|^2].$$

We check that

$$E[|\tilde{s} - x|^2] \leq 2E[|n|^2]$$

so that we can claim input quality encoding.

Entropy: We obtain an encoder with a rate of 2.08 bit for $4 \times 4 \times 4$ Walsh Hadamard, ≤ 2.45 including encoding for spectral means.

5. CONCLUSIONS

These are encouraging preliminary results and this work will be prepared for publication in the coming few months.

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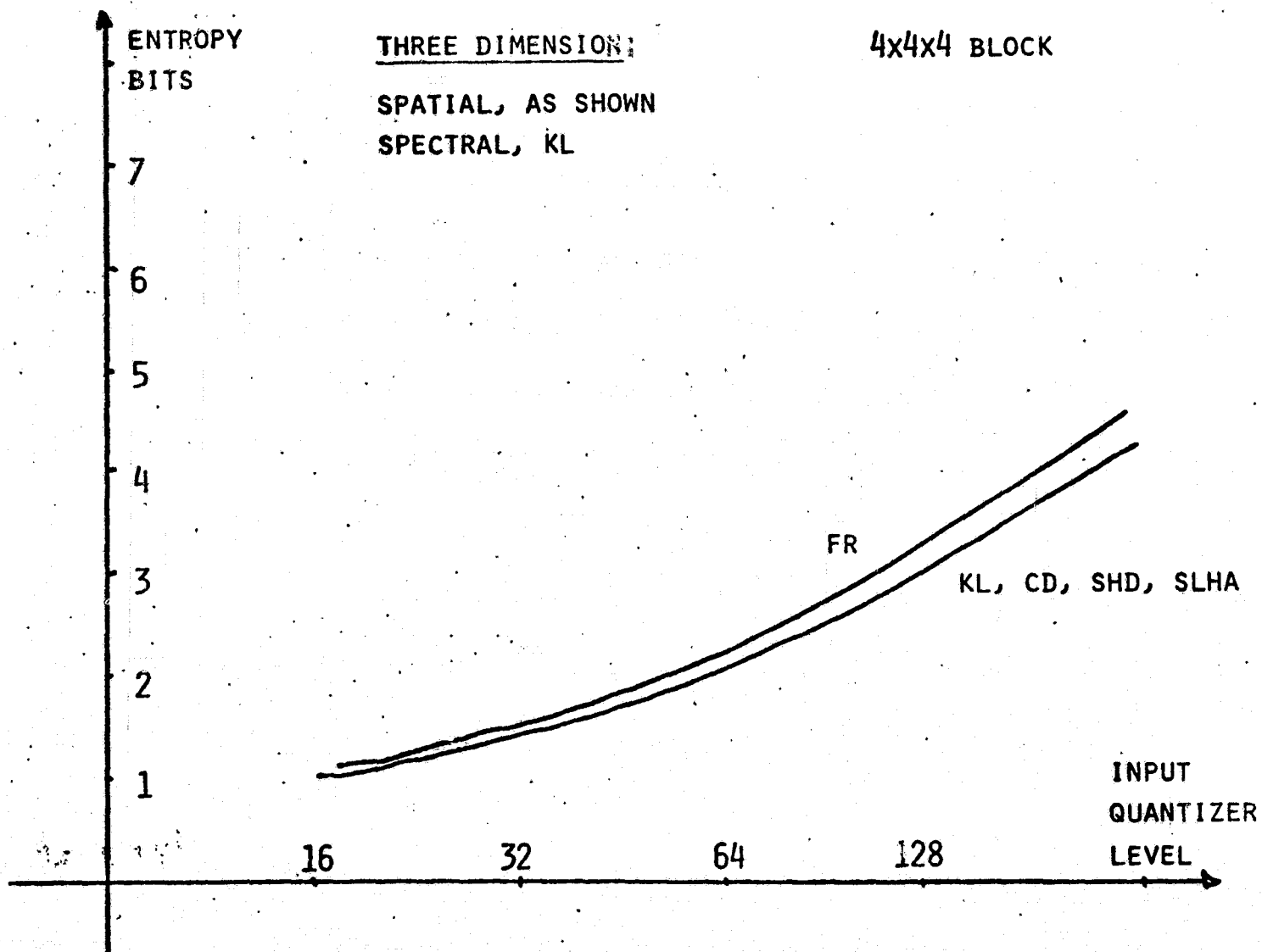


Figure 1. Plot of Entropy Bits over Input Quantizer Levels

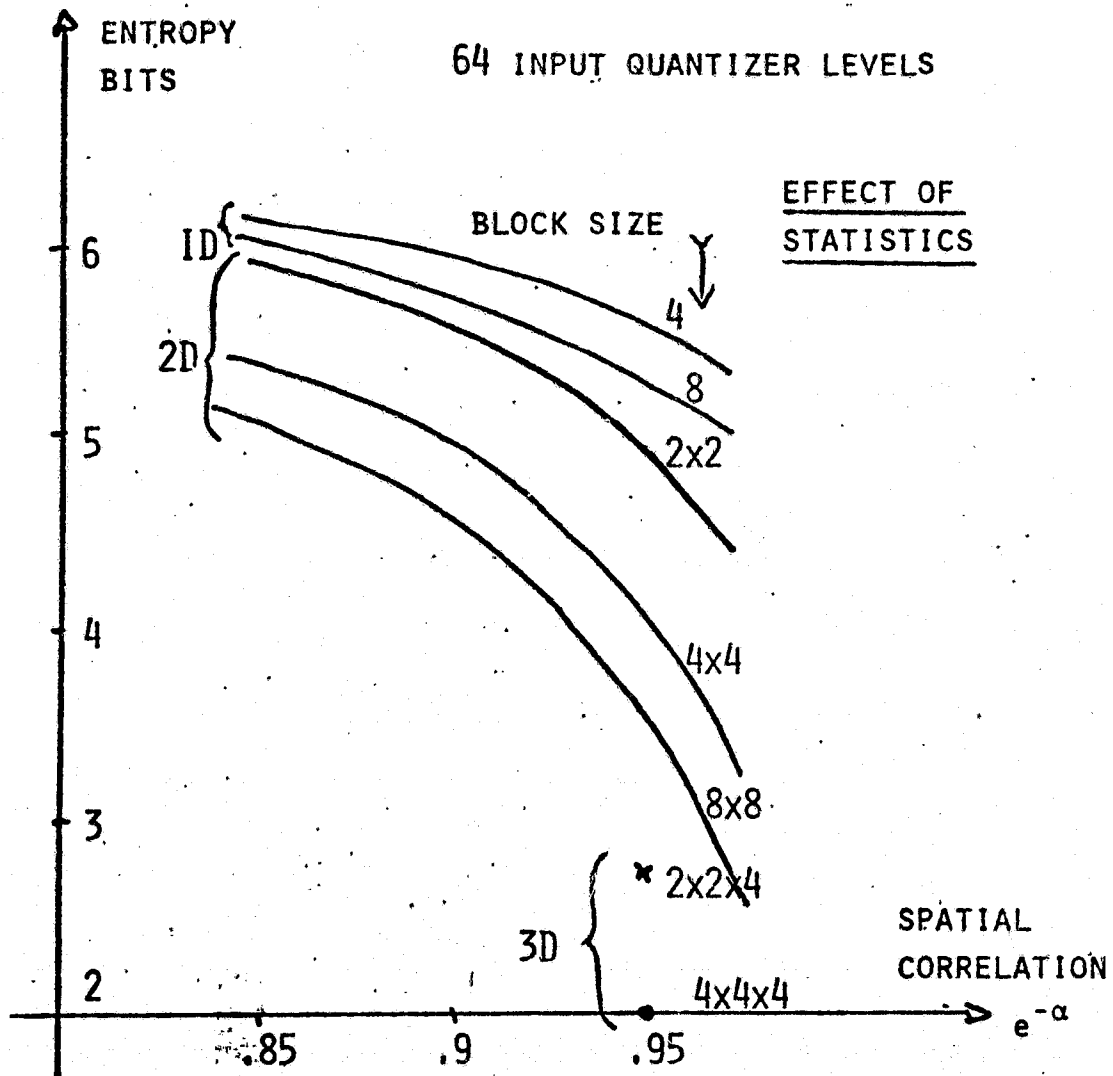


Figure 2. Plot of Entropy Bits over Spatial Correlation.

Special Study No. 5

Utilization and Assessment of Remote Sensing Data

Ida R. Hoos*

Implementation of any technological advance takes place in a social milieu. Between the technology and the society it is designed to serve there exists an important interface. Upon the nature of this interface depend how, whether, when, and by whom the technology will be utilized. In short, it is at this juncture that its future course is set. Thus, when we consider earth-oriented satellites, such as the LANDSAT series (formerly termed the Earth Resources Technology Satellite series), social scientists have a useful role to play. Working in cooperation with the scientists, they try to ascertain the social forces impinging on how and where the remotely sensed data can enter decision-making processes and how the data will ultimately affect the outcome of the decisions. This area of inquiry has received relatively little attention, and yet herein may reside the vital link between the promise of the technology and its ultimate social significance.

Some of the lacunae which exist between technological potential and utilization are illustrated in the following example. In a speech before the World Food Conference in Rome on November 5, 1974, Secretary of State Henry Kissinger made this statement:

Next year, our space, agriculture and weather agencies will test advanced satellite techniques for surveying and forecasting important food crops. We will begin in North America and then broaden the project to other parts of the world. To supplement the WMO (World Meteorological Organization) study on climate, we have begun our own analysis of the relationship between climatic patterns and crop yields over a statistically significant period. This is a promising and potentially vital contribution to rational planning of global productions.

Secretary Kissinger's reference was to LACIE (Large Area Crop Inventory Experiment), a joint program involving the National Aeronautics and Space Administration, the U.S. Department of Agriculture, and the National Oceanic and Atmospheric Administration.¹ At present the program covers only North America but the Secretary's remarks have been

*This study has been prepared by Dr. Ida R. Hoos as part of the ongoing research of the Social Sciences Group.

¹ Allen L. Hammond, "Crop Forecasting from Space: Toward a Global Food Watch", Science, 2 May, 1975, pp. 434-436.

Interpreted to suggest further expansion. When the Secretary mentions testing "advanced satellite techniques", he is still in the realm of the scientific. When, however, he talks of surveying and forecasting "important food crops," he stands at the interface with society, for food crops have clear social connotations; they are important because they feed people. Who gets fed, at what level of sustenance, and what will be the effects quantitatively and qualitatively of a better fed world population -- all these are matters of social import, and there is little agreement about them. Some participants in the Rome Conference had a gloomy outlook, expressed in the theory of "triage,"² to be applied to determine which nations should be helped. Some, like Robert F. MacNamara, President of the World Bank, condemning this notion as "morally wrong" and "technically repulsive," urged programs for stabilization of population, this being the apparent link between socioeconomic advance and decline in fertility. In all instances and from all points of view, mere advancement of factual information in vacuo was only part of a process fraught with significance.

The concept, rational planning, requires scrutiny through a social lens, for it, too, is socially defined. It encompasses history, geography, religion, culture, economics, and politics. "Rational planning" is normative. It implies an improvement over some existing practice, which is part of the "ground truth" that must be analyzed. Rationality is relative, depending on the place and circumstances. A course of action may be "rational" for one person, state, or nation and quite irrational for others. A plan may be economically "rational" and yet socially or politically disastrous. "Rational" is a perishable term; something that may seem "rational" in the short run may be quite irrational over time.

The Secretary's "rational planning of global production" is laden with even more social implications. The notion assumes the kind of world in which "rational planning of global production" has some possibility of achievement. As one contemplates relations among nations and their stance vis a vis other vital commodities, as oil, for example, one cannot but sense the gigantic proportions of this assumption. In fact, one wonders what kind of utopian world view could counteract the earthbound realities of the World Food Conference itself, where the cruel calculus of triage, self-preservation, and nationalism took precedence over humaneness, altruism, and the brotherhood of man. Too, "rational planning of global production" assumes not only some kind of consensus about production but also about distribution, pricing, and even consumption. For this we find no useful models. Even when the technological means to mount a global food watch are achieved, there still remains the need for social wisdom to manage the results.

²This French term means "sifting" and was first applied to allocation of medical aid to battle casualties, priority being given to those persons considered most likely to survive.

Secretary Kissinger's remarks and the World Food Conference serve to exemplify the importance of the interface between technology and society and of the peril of neglecting it. Our brief discussion provides a preface for this report, which is based on research being performed by the Social Sciences Group at the University of California, related organizationally and functionally to the U.C. Berkeley Remote Sensing Research Program, and all part of a five campus Integrated Project conducted under NASA sponsorship.³ Its participants include such disciplines as hydrology, forestry, agriculture, geography, engineering, economics, and sociology. Working in tandem with the scientific groups, the Social Sciences Group has been studying the social conditions, environment, and impacts of remote sensing for management of water resources in California. Our specific interest is the utilization aspects of data derived from LANDSAT and subsequent satellites and other remote sensing vehicles. From our research findings we hope to derive insights which will prove relevant to technology assessment and utilization in general.

The promise of remote sensing is great, but the potential can be realized only if implementation occurs and proper and full-dimensioned assessment is achieved. These are social problems, and the social scientist must "map the social landscape," much as the remote sensing expert establishes ground truth, to ascertain the why's and wherefore's of application and utilization. Interesting to note in this connection is NASA's official recognition that these aspects of its programs merit study along with the technical. Unique among government agencies, NASA has long fostered the multi-dimensional appraisal which only recently, under the rubric "technology assessment," has become generally recognized as necessary, and, under the mandate of environmental impact assessment, a legal requirement.

The ongoing research by the Integrated Project focuses on California's water resources. Always essential, astute management of water becomes ever more critical because of the uncertain future of a number of factors with which it is intimately related. Many of these are clearly social as can be seen in the list of issues compiled by the California Department of Water Resources in its effort to design a framework for future planning. They are as follows:

- 1) shifts in patterns of demography, e.g., lower birth rates, migratory movement of population;
- 2) expanding world agricultural markets, e.g. Russia, China, and the less developed countries;

³NASA Grant NGL 05-003-404, "An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques."

⁴A clue to the interest and effort already devoted to the subject can be obtained from reference to the following: Mark A. Shields, Social Impact Assessment, A Report Submitted to the U.S. Army Engineer Institute for Water Resources, IWR Paper 74-P6, October, 1974.

- 3) more stringent air and water quality standards and regulations;
- 4) changing policies on land management and usage;
- 5) greater concern for environmental preservation and enhancement.⁵

Another key issue in water policy devolves on its relationship to energy, both with respect to consumption and production, and here the future, near and distant, is uncertain. However the United States achieves some degree of independence from foreign sources, whether through conservation or technological breakthrough, water will play a decisive role both as consumer and producer of energy. Of immediate concern already is the siting of power plants, the use of coasts having been restricted and inland locations requiring considerable amounts of fresh cooling water.

The specific objectives of the Social Sciences Group are to identify, define, and refine the user role in the integration of remotely sensed data in water management. This mandate is consistent with and anticipates by some years the observations and recommendations of the prestigious Committee on Remote Sensing for Earth Resources Surveys (CORSPERS)⁶ in their recent report:

Remotely sensed information ultimately must find its way to a multiplicity of final users. These may be found at all levels in government, private industry, and university groups. For example, the field of water resource management and the issues of land use mapping and land use planning affect many federal, state, and local and private agencies.

The Committee recommends that an institutional communication link be established between resource and environmental data users at the state and local agencies and in private industry with responsible federal agencies.

While the Social Sciences Group may not be able to forge that link, it works toward understanding and establishing the channels of communication which must precede it. In cooperation with the scientific and technical members of the California Integrated Project, we study the institutions and mechanisms through which water policy decisions in California are made. We therefore concern ourselves with the decision-makers, the ways in which decisions are made, the kinds of decisions that must be made and by whom, the data used and that which might be potentially useful in making and implementing decisions. Actual and potential

⁵State of California, The Resources Agency, Department of Water Resources, The California Water Plan -- Outlook in 1974, Bulletin No. 160-74, pp. 45 ff.

⁶National Academy of Sciences, Commission on Natural Resources, Remote Sensing for Resource and Environmental Surveys: A Progress Review - 1974, Washington, D.C. 1974, pp. 38 and 39.

receptivity toward new data sources is of special interest; here we assess such matters as 1) the conditions for receptivity, i.e. reliability, specificity (readiness of applicability), ease of access and the like; and 2) means and methods by which users arrive at decisions about new technologies, e.g. benefit-cost analysis. By identifying and establishing working rapport with the persons engaged in managing California's water resources we explore these matters so as ultimately to gain a better understanding of the ways in which remote sensing and related technology can be linked into and made responsive to user needs.

The approach of the Social Sciences Group is practical and pragmatic; we seek no dazzling theoretical or methodological breakthroughs. While we engage in no simulation exercises and expect to derive no magic models, we deem it our obligation to draw upon our discipline and experience to examine and evaluate those being offered as justification for courses of action taken or proposed. In addressing the political and socio-economic aspects of water management, we seek to identify the real-life dimensions involved in decision making. In our view, these are the sine qua non in public policy formulation and far supersede parochial and doctrinaire considerations.

To identify the decision makers in California water management and to discover the kinds of decisions made is a task not too well or adequately served by reference to formal organization charts or tables. There exist a multitude of separate entities, which include agencies of the state and federal governments, local public bodies of many types, and departments of local governments. There is also the bureaucratic infrastructure, which interacts with appointed boards and commissions and treads a precarious course through the sometimes conflicting jurisdictional levels. There is, moreover, the informal management structure, where "channels" are bypassed and actions taken with only token reference to "the book". In government as in industry, a great deal is accomplished, or stymied, by this mechanism. Added to this are the wholly personal biases, preferences, prejudices, and predilections of managers. Idiosyncratic, usually unpredictable, and often subliminal, these factors are crucial in the decision-making process.

These observations should surprise no one who has any familiarity with large scale organizations and, more specifically, with a network of them, such as California's water industry. Who has authority and what are the specific areas of responsibility reflect a long history in California policy and politics, with economic overtones, legal ramifications, and sociological underpinnings. The huge literature on all these aspects attests to the complexity of water management and warns against too facile reliance on "the decision-maker" as anything but a convenient fiction or "the user community" as something other than a servicable construct. This caveat is offered because of the tendency on the part of persons who would promote LANDSAT and other technologies to aim at too broad and amorphous a target.

Conditions for Receptivity

In the case of a new technology, chances for successful transfer appear to be the more favorable the more specific is the application. The reason for the axiom is clear almost to the point of redundancy; a new technology must prove itself in each instance of use. And the "proof" must show up in relatively short time and must be fairly tangible. As we shall see later in this paper, when we discuss evaluation methods, these conditions explain the popularity of benefit-cost studies of the kind that lend themselves to an assembling of supportive "facts" and thus provide a kind of quick rationale. Ideally, assessment should be conceived of in broader terms, in a longer time frame, and embracing many classes of effects that surpass conventional benefit-cost calculations.

To illustrate the case for specificity, we have selected an ongoing activity under the University of California Remote Sensing Center. This has to do with the use of satellite imagery, in conjunction with appropriate supporting aerial photography, for snow survey work. At present, the California Department of Water Resources conducts a cooperative snow survey and water supply forecasting program with some fifty agencies and organizations providing personnel and monetary support for field work and collection of data. Snow measurement courses, aerial snow depth markers, and automatic snow sensors are the devices used. While a number of authoritative studies^{8,9,10} point to the likelihood of areal extent of snow as a valuable parameter in improved stream flow forecasting, major obstacles have been costs of acquiring data for large areas at the required level of accuracy.

The Remote Sensing Research Program at Berkeley has undertaken the evaluation and testing of remote sensing techniques for estimating areal extent of snow on LANDSAT imagery. Using U-2 and light aircraft photography and ground data to develop a suitable reference document, the group is developing a technique involving interpretation and analysis of satellite imagery designed to provide an estimate of areal extent of snow over 2.1 million acres (850,000 ha) in the Feather River Watershed. So that there may be confidence in the accuracy of the estimates, supporting interpretation techniques have been devised and statistical

⁷Under NASA grant NGL 05-003-404, as part of the Integrated Project.

⁸D. Baker, "Remote sensing of Snow Fields from Earth Satellites," in International Workshop on Earth Resources Survey Systems, National Aeronautics and Space Administration, NASA SP-283, May 3-14, 1971.

⁹James C. Barnes and C.J. Bowley, "Satellite Photography for Snow Surveillance in Western Mountains," in Proceedings of the 37th Annual Meeting of the Western Snow Conference, Salt Lake City, 1969.

¹⁰Charles F. Leaf and Arden D. Haeffner, "A Model for Updating Stream-flow Forecasts Based on Areal Snow Cover and a Precipitation Index," in Proceedings of the 39th Annual Meeting of the Western Snow Con-

procedures applied. The ultimate objective of this demonstration exercise is to explore the cost-effectiveness of LANDSAT-type data in snow survey work, which contributes to water supply forecasting.

Another activity being performed under the Remote Sensing Research Program at the University of California, Berkeley exemplifies further the way in which the reliability of remote sensing as a data source in resource management is being established. The research group set for itself the "first case" task of performing a timber inventory estimating the standing volume of salable timber within a designated district of 215,000 acres in the Plumas National Forest and, in the process, to accomplish these additional objectives: (1) test the operational efficiency of the sampling procedures of the multistage sample design; (2) test the effectiveness of the CALSCAN¹¹ classifier on the LANDSAT data; (3) to determine the value of LANDSAT data and aircraft data in reducing the sampling error; and (4) to compare the costs of this timber inventory with those for an equivalent inventory using conventional procedures.

Having demonstrated the usefulness of a LANDSAT-aided multistage sampling system for a single Ranger district, the research group has now enlarged the area, to cover the entire Plumas National Forest, some 1,162,000 acres, and expanded the parameters to include volume, growth number of trees, subdivided into species and size classes. In addition, estimates have been sought for the entire forest, ranger districts, and by major vegetation types and stand condition classes. Careful analysis of the use of remotely-sensed data has demonstrated the importance of this technology in timber management in terms of its present cost-effectiveness and ultimate potential as future research provides methodological sophistication and refinement.

When a new technology is being offered as a potential substitute for and possible improvement over conventional methods, demonstration of reliability is, as we have indicated, a first priority. Then, a number of factors loom as determinative in the transfer process. One of these is the time element in availability of the data. If one of the assets of remotely-sensed information and, hence, its advantage over customary sources, is timeliness, then channels for dissemination are essential. The delivery system in current operation is cumbersome. Under present arrangements, there is a delay of as much as six weeks between receipt of the LANDSAT data and the time they are processed

ference, Billings, Montana, 1971

¹¹ J.D. Nichols, M.J. Gialdini, S.J. Titus, J.S. Sharp, B. Orme, R.W. Thomas, and D.T. Lauer, "ERTS [LANDSAT] Application in Timber Inventory: A Summary of Two Case Studies," Special Presentation for NASA Forestry Applications Program Semi-Annual Review, Berkeley, California, February 26, 1975.

and sent by Goddard Space Flight Center to Sioux Falls, South Dakota. Another two months may pass before the user can get a LANDSAT image from Sioux Falls, or up to four months if a computer tape has been ordered. Potential customers, like managers of agricultural lands, watersheds, and rangelands, have probably been deterred from using LANDSAT data because of the time lag, since their operations require up-to-date input. A recent Fortune article compared NASA, in this respect, to a Soviet department store,¹² "where customers stand in interminable lines to get their purchases."

Speed of availability and efficiency of distribution are vital factors in the coupling of any technological innovation to socially useful purposes. This is almost axiomatic and has particular relevance where information technology is concerned. Acceptance of LANDSAT and related satellites as a source of information has been further handicapped by another situation, this one peculiar unto itself, viz., LANDSAT's own survival and the uncertainty that, even after convincing demonstration of its capability, it can assure continuity of data delivery. The CORSPERS Report, mentioned earlier, stressed some of the negative effects of the unsettled future of the satellite program:

Any user who requires data continuity and suspects that it may not be maintained will be reluctant to forsake his present information sources, even if inferior, to become dependent on remotely-sensed data. Similarly, a user now in the program who subsequently suffers a break in his data continuity may¹³ be very difficult to entice back into the program at a later time.

Strongly affecting receptivity toward a technological innovation is ease of access, a factor of special importance in information technology because of its predominantly invisible and intangible character. This point concerns not the efficiency of the delivery system, already discussed above, but openness of access. Prospective users almost invariably ask about the secrecy associated with gathering and dissemination of LANDSAT data and express great relief when they learn that there are no screening procedures, no security regulations, no restrictions on usage of the information. For one brief period in LANDSAT's history this very policy of openness created a severe problem in its delivery system. When, late in 1973, Eastman Kodak Company ran a series of magazine advertisements exhorting the public to "see your home town

¹²Gene Bylinsky, "ERTS Puts the Whole Earth Under a Microscope," Fortune, February, 1975, pp. 128 and 130.

¹³Committee on Remote Sensing Programs for Earth Resources Surveys (CORSPERS), Remote Sensing for Resource and Environmental Surveys: A Progress Review, 1974, op. cit., p. 22.

from space," the enthusiastic burst of one-time curiosity orders overburdened the facilities of the EROS Data Center and caused further delays for serious users.¹⁴ This little episode illustrates the point that anyone who wants LANDSAT imagery may acquire it. He simply fills out the forms supplied by the EROS Data Center. Instruction sheets are available, as is the Data User's Handbook. Readily-accessible data-logs list offerings and prices. All that is required of the user are such routine items as name, address, zip code, and mode of payment.

Openness of access is stressed here because of a recent budgetary controversy over the future of civilian satellites. According to the "reliable sources" upon which the press usually draws, especially when a debate has taken place behind closed doors in the Office of Management and Budget, some Government officials maintained the view that military satellites could gather information about natural resources in the course of their other duties, and, perhaps, at lower cost than and with certain technical advantages over the LANDSAT series.¹⁵ The merits and demerits of military as opposed to civilian hardware are not strictly relevant here. Suffice it to say here that one argument is based on economy, watchdog agency spokesmen being prone to raise questions about spending more taxpayers' money on space imagery that is of lower resolution than that of military satellites, which will continue to be flown. The counter argument rests on the special characteristics of LANDSAT-type systems, which are said to provide more of the kind of information needed in resource management. Moreover, proponents for the latter program point out, follow-on launchings of LANDSAT-type satellites show a substantial decline in cost, from the initial large investment in LANDSAT I and II to the relatively small cost-per-shot. It is clear, then, that we find authorities taking diametrically opposed stands even on the technical aspects of the debate. Our interest is primarily the social factors influencing receptivity toward remotely-sensed information, and what is germane here is openness of access.

The reality of the case for LANDSAT data may be contrasted with a hypothetical case involving information from a military satellite. We must dwell in the realm of hypotheses when we discuss the military, because at present only several civilian agencies are permitted to enter the classified facility and use non-secret materials for making specified resource decisions and we encountered extreme reticence about procedures for gaining access to the data. Other agencies reported that

¹⁴Testimony of Senator James Abourezk, Hearings Before the Subcommittee on Space Science and Applications of the Committee on Science and Astronautics, U.S. House of Representatives, Earth Resources Survey System, 93rd Congress, Second Session, October 3, 4, and 9, 1974, p. 83.

¹⁵David F. Salisbury, "Budget Pinch Threatens Nonmilitary Spacewatch," The Christian Science Monitor, January 21, 1975. It may be noted that a proposed third launching was the subject at issue, and not LANDSAT 2, which had already been funded at that time.

there are "no visible mechanisms" for screening clearance or that if any exist, they are not generally known.

As has just been seen, LANDSAT Imagery, by contrast, can be ordered like merchandise from a Sears Roebuck catalog. Before trying to envision present practices for access to data from a military source we should indicate that, despite recommendations alleged to have come from the Office of Management and Budget that the Department of Defense carry on civilian resource survey work as a sideline, the DOD has not responded publicly. It may be, as one official suggested, the DOD's historic posture vis a vis intelligence activity of any kind, let alone mapping at home and abroad via satellite or some other "spy-in-the-sky" mode, will prevail. This has been one of categorical denial, even in the face of public disclosure and discussion.^{16,17} Despite arguments in favor of economy of operation and against duplication of hardware, the military might very likely opt for steering clear of an expanded civilian service function, so as to maintain its own secrecy and to avoid the inevitable poor public relations that could result when users' requests for data were subjected to military screening procedures and, perhaps, denied.

Let us, then, construct our hypothetical case, based on the information we have been able to glean about civilian agencies which have used military sources for their survey data. To begin with, the prospective user must have official clearance. To obtain this he fills out DOD form number 22-R-46, called "Personnel Security Questionnaire." This asks for the following items, among others:

- Names - last, first middle, present and former, and aliases;
- Date and place of birth - self; spouse, former spouse(s), brothers, sisters, and children. Also, living relatives of self and spouse not U.S. Citizens;
- Education; military service, location of Draft Board;
- Organizational membership (except labor unions and those in subversive category specified later);
- Foreign countries visited or resided in, with length and purpose of stay;
- Foreign government, firm, corporation, or person for whom you act or have acted as a representative, official, or employee in the past five years;
- References, remarks.

¹⁶ Ted Greenwood, "Reconnaissance and Arms Control," Scientific American, February, 1973, pp. 14-26.

¹⁷ Luther J. Carter, "Strategic Weapons: Verification Keeps Ahead of Arms Control," Science, March 14, 1975, pp. 936 ff.

(The following sections of the questionnaire are considered "privileged information between you and the Government.")

Arrests -- for any violation of the law, regulation, or ordinance -- all charges, even if they were dismissed, are to be listed, including traffic violations with a penalty of \$25 or over;

Type of discharge, if any, from military service;

Record of security clearance suspended, denied, or revoked;

Mental or nervous disorders; use now or ever of habit-forming drugs; chronic use to excess of alcoholic beverages -- with names and addresses of hospitals, clinics, doctors, etc.

Organizational membership in Communist groups, associations which are totalitarian, Fascist, Communistic, or subversive, or which has adopted, or shows, a policy of advocating or approving the commission of acts of force or violence to deny other persons their rights under the Constitution of the United States or "which seeks to alter the form of government of the United States by unconstitutional means."

The forms are submitted along with a card prepared by the Federal Bureau of Investigation for recording applicants' finger prints.¹⁸ Then, the potential user must establish definitively his "need-to-know" - another DOD requirement, satisfied by submitting his specific information request in terms of the resource decisions to be made. Just how the need-to-know is judged and by whom we could not ascertain. Therefore, we can offer no guidelines on preparing a persuasive case for need. The data are accessible for use only within a classified facility and interpretation is done in the premises; nothing is allowed out of the compound. The imagery to which the user will ultimately be given access then has to be "pre-sanitized" by the military. In fact, it must be of such a nature that it can be so shrouded that neither the source nor the accuracy discloses the system which produced it. This stricture constitutes a serious disadvantage to serious research, since it violates some of the basic requirements for professional procedure, such as proper reference to and identification of sources.

Since there exists at present no visible interface with the military, and therefore no mechanism for access, the situation we have described has been reconstructed from interviews with officials who speak from experience. If there are at present different avenues by which access to data from military satellites can be achieved, they are so swathed in secrecy or so obscured by protocol and elaborate procedures as to be virtually impassable. Assuming, as we do, the position that utilization of remote sensing technology is a desirable objective, then axiomatic among conditions for receptivity are ease and freedom of access. On this score, the present situation is as follows: EROS,

¹⁸ FBI form FD-258

is willing -- but not able. Its present dissemination system acts as a deterrent to widespread acceptance. The military, on the other hand, is not willing, and we cannot even try to assess its ability to deliver. The situation is not static however; the current difficulties are not insurmountable. EROS will improve in operational efficiency. The data management system will be altered, with a better flow from the sensing of data to its application by the user.¹⁹ Policy changes may occur in the military. As the state-of-the-art of satellite technology advances and knowledge expands, the rationale for secrecy will decline. If, as we have seen, the Department of Defense²⁰ can declassify photographs of reentry vehicles from a Soviet missile, can views of Russian wheat fields be far behind? Moreover, when the global embrace and dimensions of satellite technology are taken into account and its international implications come to the fore, openness will be a distinct asset in overcoming the "super-spy" notion.^{21,22}

Means and Methods of Assessing New Technologies

In an era when technological progress has been spectacular, social process seems all the more laggard. The mismatch, while long familiar to anthropologists and sociologists, has a plausible explanation. The lag can, nonetheless, be burdensome to public administrators who are expected to move with the times and yet operate within the same time zone as the public they serve. How to select from the cornucopia of offerings those which will prove useful and beneficial, by whose standards such judgments are to be made, on whose expert advice to rely -- these are matters that demand attention if the fruits of science and technology are to be integrated into public policy on a truly informed basis.

Earlier in this paper, we discussed certain conditions influencing the acceptance of remote sensing in particular and new technologies in general. Implicit in all of the criteria -- specificity, reliability, availability, accessibility, and the like -- were elements of technology assessment. When resource managers adopt or reject a technological innovation, they have, presumably, made some kind of assessment. The notion is not new. The Flemish weavers applied it when they

¹⁹Report No. 93-983, Authorizing Appropriations to the National Aeronautics and Space Administration, House of Representatives, 93rd Congress, Second Session, April 10, 1974, pp. 83-84.

²⁰Luther J. Carter, op. cit., p. 937.

²¹Donald F. Salisbury, "Satellite Photography: Helping Underdeveloped Countries," Christian Science Monitor, January 24, 1975.

²²"U.S. Will Continue U-2 Run in Europe," The New York Times, May 31, 1975.

gave bad cess to the spinning Jenny and hurled their sabots into the looms!²³

What is interesting in the present context is the reentry on the national scene of the concept technology assessment and its re-attribution. For example, in 1969, the National Academy prefaced a report as follows:

The phrase "technology assessment" was first introduced by Congressman Emilio [sic] Q. Daddario, Chairman of the Subcommittee on Science, Research, and Development, to characterize the sociotechnical research that discloses the benefits and risks to society emanating from alternative courses in²⁴ the development of scientific and technological opportunities.

This statement is as fuzzy as to objective as it is cavalier in its treatment of grammatical and typographical accuracy. Emilio Daddario had, to be sure, polarized attention on the growing scientific and technical content of legislative issues, for he had been concerned that therein lay a capacity for both good and harm. He proposed a program of assessment that would "enable decisions for the public good"²⁵ through better rapport between Congress and the nation's scientific community.

Daddario's efforts received widespread support for a number of reasons, some of them paradoxical: (1) Faith in science and technology was part of the American credo; therefore society, faced with complex problems, could turn to its scientific and technical reservoir for salvation; (2) Science and technology were not an unmitigated blessing; in fact, possibly attributable to their skewed development was the "civilizational malaise"²⁶ of our time. Hence, their possible impacts needed to be scrutinized critically before irreversible commitments were made.

²³ This action did not materially affect the course of the Industrial Revolution, although it did contribute the useful word, sabotage, to the vocabulary of the worker.

²⁴ U.S. House of Representatives, Committee on Science and Astronautics, A Study of Technology Assessment, July, 1969, p. 1.

²⁵ Statement in U.S. House of Representatives, Technology Assessment Seminar, Proceedings before the Subcommittee on Science Research and Development of the Committee on Science and Astronautics, Nineteenth Congress, First Session, September 21 and 22, 1967, p. 2.

²⁶ Robert L. Heilbroner, An Inquiry Into the Human Prospect, New York, W. W. Norton, 1974.

Technology assessment was to be rediscovered many more times²⁷ and, in the process, to undergo considerable institutionalization. Congress held hearings and formed the Office of Technology Assessment; the Department of Commerce set up its own Office of Technology Assessment and Technological Forecasting. Enactment of the National Environmental Policy Act of 1969, with its requirements for environmental impact statements, actually legislated technology assessment. Section 102 of the Act specifies that an impact analysis must be made in the project-approval stage, especially if the course of action under review is of a technological nature. College curricula, built around the theme, blanket the country, with everything from engineering to political science joined in interdisciplinary effort. Learned societies, national and international, ponder the problems and publish papers. New journals on the subject appear and old ones devote whole issues to technology assessment and attendant concerns. All these earnest endeavors are abetted, if not inspired, by generous infusions of money from government and foundation sources. Technology assessment has become the gravy train that attracts many riders from a wide range of disciplines, capability, and, deplorably, integrity. During the decade since Daddario "introduced" technology assessment, the term has taken on ubiquitous dimensions and ramifications, among which have been observed the rise and fall of science advisory committees, the growth to epidemic proportions of benefit-cost methodology, and the emergence of technology-predictive tools as part of the futurology kit.

As to the functioning of science advisory committees, the assumption that scientists would "apply the scientific method"²⁸ and would thus guide the perplexed with objective wisdom proved unwarranted. Science is not without bias and scientists have ideologies. In the orchestration of the advisory process the traditional advise-and-consent was often reversed. Consent-and-advise seems to have been the order of procedure, with recognition given to those scientists whose views were known to be consistent with or supportive of those of the current Administration. Many of the nation's eminent scientists have avoided the public arena to protect themselves from embroilment in partisan politics. Science advisory committees have sometimes found themselves in the position of the messenger who bears ill tidings. They may not have been beheaded for offering unpopular advice, but they were emasculated.

Although scientists have not been universally honored, "the scientific method" has been apotheosized. Quite contrary to scientific tenets, however, which call for rigorous definition, the term is applied to an

²⁷ Edward A. Wenk, Jr. "Managing Technology for a Humane Society," The Trend (Engineering, University of Washington) Vol. 26, No. 2, April, 1974. p. 5.

²⁸ Daddario, op. cit., p. 2.

eclectic amalgam of techniques derived mainly from operations research and systems analysis and, therefore, basking in a borrowed glory because of their prestigious heritage in defense and space management. Accorded credibility because they are "rational" and "scientific", the tools and analytic procedures have been offered almost evangelically as the way to assess the impacts, present and future, of technology, even though their demonstrated appropriateness for and achievements in public policy-making are dubious.²⁹

Benefit-cost analysis, one of the techniques, has come to represent the primary ingredient, if not the sum total, of the assessment process. Expedient because it yields a quick and quantified answer, the benefit-cost analysis, for all its limitations, is the evaluative method most commonly utilized here as in other areas of public policy. As such, it is not new, its origins residing in the Flood Control Act of 1936,³⁰ which authorized the initiation of river and water shed improvements "if the benefits to whomsoever they may accrue are in excess of the estimated costs." Since that early beginning, reliance on benefit-cost analyses by Congress and government agencies at all levels has increased to the point that programs and projects are rarely authorized until subjected to this kind of analysis.

As experience has grown, however, some disenchantment has set in. Economists have pointed out the limitations, and criticism has³¹ focused on use of the techniques in the management of water resources. The General Accounting Office conducted a survey of a number of federal bureaus and agencies which used benefit-cost analyses in project justification and summarized the criticisms as follows: (1) benefits were not computed in a consistent manner; (2) benefits were not based on an analysis of conditions with and without the project; (3) benefit computations were not adequately supported; and (4) project costs and in-

²⁹ Ida R. Hoos, Systems Analysis in Public Policy, Berkeley, University of California Press, 1974.

³⁰ U.S. Statutes-At-Large 1510 (1936)

³¹ For example, Otto Eckstein, Water Resources Development: The Economics of Project Evaluation, Cambridge, Mass., Harvard University Press, 1958

J. Hirshleifer, J. deHaven, and J. Millman, Water Supply: Economics, Technology, and Policy, Chicago, Illinois, University of Chicago Press, 1960.

N. McKean, Efficiency in Government through Systems Analysis: With Emphasis on Water Development, New York, John Wiley, 1958.

Steve H. Hanke, "Benefit-Cost Reconsidered: An Evaluation of the Mid-State Project," Water Resources Research, Vol. 10, No. 5, October, 1974, pp. 898-908.

duced costs were not fully considered in the benefit-cost determinations.³²

Hanke's analysis of the Bureau of Reclamation's benefit-cost analysis reveals discrepancies in estimated costs and benefits sufficient to have altered radically the decisions about projects. The tools of economics lead, in these instances, to very divergent conclusions. And this will always be so, because, as he says, "analysis is filled with both disputes over basic assumptions and widely divergent choices as to the 'correct' solutions to difficult issues such as level of interest rates, the value of wildlife, the effect of government programs on agricultural markets, and the impacts of political and administrative expedients. Although benefit-cost analysis can enlighten us on these issues, it does not provide us with an unambiguous technical solution to public expenditure decisions. In spite of years of refinement in the theory of benefit-cost analysis no one has succeeded in making it impartial or indisputable."³³

Remote sensing, as a new technology, is being subjected to these forms of assessment; benefit-cost analyses are used as means to justifying the continued development and operation of LANDSAT-type satellites as well as to the adoption of remotely sensed data for specific resource management applications. Unfortunately, both types of evaluations have evoked exercises assigned merely to dazzle Congress or cover the law. Manipulation of costs, unsubstantiated assumptions of benefits, arbitrariness of selection of variables, objectives, and criteria, doubtful credibility of "facts", and built-in advocacy have all contributed to demonstrations of technical virtuosity. As guideposts to "rational" decision-making the benefit-cost figures produced were highly questionable. They were more likely to satisfy a point of view or discharge a consultant's contract obligations quickly and neatly than to serve a social need. In a recent book,³⁴ Brewster Denny makes the important observation that decision-making technologies that may have proven useful in certain aspects of business management are not useful at levels above the firm.

Government is not an industrial engineering problem, a systems analysis problem, a business management problem, a market analysis problem, nor is it a conglomerate of all the skills and techniques which have been designed to deal with such problems carefully packaged and modified to operate in a slightly different environment.

³² Comptroller General of the United States, Improvements Needed in Making Benefit-Cost Analyses for Federal Water Resources Projects, Report to Congress, September 20, 1974, p. 12.

³³ Hanke, Op. cit., pp. 906-7.

³⁴ P.C. Ritterbush, ed., Technology as Institutionally Related to Human Values, Washington, D.C., Acropolis Books Ltd., 1974.

The outlook³⁵ is not altogether bleak, however. The Comptroller General's report³⁵ suggests that the era of cavalier treatment of the assessment process by obedient consultants and accomodating academics may be coming to an end. In the case of LANDSAT and related satellites, to predicate estimation of the value ultimately to be derived from the data on patently flimsy calculations is to court embarrassment at the review stage. Congress and funding agencies, once prone to gullibility so long as the benefit-cost format was used and numbers plugged in, are becoming more sophisticated. They recognize that a wary public will not accept a numbers game in the form of an econometric model of dubious validity or an absurdly precise benefit-cost ratio when long-range and intangible desiderata are at stake. More persuasive and credible than analyses conjured up as proof of capability or potential of LANDSAT-type technology are such evaluations as that performed by the National Academy of Sciences' Committee on Remote Sensing for Earth Resources Surveys (CORSPERS), whose work was mentioned earlier in this paper.³⁶ Concerned with the scientific value and the relevance of LANDSAT-type data to earth resource management and environmental monitoring, CORSPERS produced a report comprehensive in scope and searching in depth. With remarkable economy as to pages, a conspicuous disdain for padding, and no charts and tables, their evaluation of remote sensing technology and their recommendations is a refreshing antidote to the psuedo-mathematical macrame that dominates and violates the inherently social process of technology assessment.

³⁵ Remote Sensing for Resource and Environmental Surveys: A Progress Review - 1974, op. cit.

³⁶ Op. cit.

SPECIAL STUDY NO. 6
STATEMENT BEFORE THE INTERIOR SUBCOMMITTEE
OF THE
APPROPRIATIONS COMMITTEE
U. S. SENATE
NINETY-FOURTH CONGRESS

by

Robert N. Colwell
Associate Director, Space Sciences Laboratory
University of California

May 13, 1975

Mr. Chairman and Members of the Subcommittee:

It is indeed a pleasure for me to address this Committee relative to needs at the EROS Data Center for rapidly processing LANDSAT data into products of suitably high quality for use in making inventories of natural resources. My remarks will be based both on my familiarity with present EROS data products and on experience which I have had during the past 35 years in developing improved methods for making inventories, (by means of remote sensing and associated field work) of such natural resources as timber, forage, soils, water and minerals. As your Committee well knows, these are among the natural resources that are of primary concern to personnel in the U.S. Department of Interior.

The term "inventory", as used in my presentation, will pertain to the act of determining the amount and quality of each of the above-mentioned resource types present in each portion of the area that is of interest from the resource management standpoint. The term "LANDSAT" will pertain to the recently renamed family of unmanned spacecraft that are especially designed to acquire remote sensing data of a type that will facilitate the inventory of natural resources. Hence that term will include spacecraft previously referred to as ERTS-A (ERTS-1); ERTS-B (ERTS-2); ERTS-C (ERTS-3) and EOS (ERTS-4). Hereafter, in my presentation, these vehicles will be referred to respectively as LANDSAT 1, 2, 3 and 4. The emphasis that will be placed in my remarks on the above mentioned needs as they exist specifically at the Interior Department's EROS Data Center in Sioux Falls, South Dakota, is occasioned by the fact that the capability for making inventories of various natural resources (largely with the aid of LANDSAT data) is being concentrated to an increasing extent within that Center.

The importance of maximizing the Interior Department's capability for making timely accurate resources inventories can be clearly conveyed to a Committee as knowledgeable as yours merely by my setting forth the following brief 5-part statement of facts:

- (1) whether on a local, regional, national or global basis, the demand for most natural resources is rapidly increasing at the time when their supply is rapidly dwindling and/or their quality is rapidly deteriorating;

- (2) it therefore is becoming increasingly important for the Interior Department, and all other resource management agencies, to manage as intelligently as possible those natural resources with which they have been entrusted;
- (3) an essential step leading to the intelligent management of such resources is that of making accurate resource inventories at suitably frequent intervals, (a process known as 'monitoring');
- (4) because of some very remarkable technological developments that have occurred in the field of remote sensing since the dawning of the space age, such inventories usually can best be made in the future by using, as the primary data input, remote sensing data acquired from spacecraft of the LANDSAT type, and
- (5) because of the dynamic nature of certain natural resources, the inventories need to be made as promptly as possible following acquisition of the LANDSAT data.

The specific examples dealt with in the remainder of my presentation seek to document the extent to which the quality of the Interior Department's "quick-look" resource inventories, and therefore the effectiveness of its resource management activities, need to be improved through the development of capabilities at the EROS Data Center for rapidly processing LANDSAT data into products of suitably high quality for use in making such inventories.

It is to be emphasized that the improvements about which I will be speaking are not those that conceivably might be made within the LANDSAT vehicles, themselves, nor even within their on-board remote sensing systems. Instead I will speak solely of improvements that need to be made on the ground with respect to the quality and speed of processing of LANDSAT-acquired remote sensing data, once telemetered to the earth and recorded on magnetic tape in digital form. Furthermore, the particular improvements about which I will be speaking are not those that conceivably might be made through the use of very time consuming and laborious processing techniques, beneficial though they might be for certain purposes. Instead, I will address myself solely to improvements that need to be made in order to improve data analysis capabilities in the short term, i.e. within the first few hours after the receipt of remote sensing data from a LANDSAT vehicle, the better to monitor changes that have occurred in certain resource attributes since the last previous resource inventory was made.

The improvements would be of two major types in that they would be designed to provide either (1) better visual displays, or (2) better computer-compatible tapes.

SPECIFIC EXAMPLES

The examples which follow deal with most of the types of natural resources for which the Interior Department has either major or very significant management responsibility throughout the United States.

1. FOREST AND RANGE RESOURCES

A. Monitoring the Health and Vigor of Timber Stands

Such damaging agents as fire, insects and pathogens can destroy entire timber stands in large forest areas unless these agents are quickly detected and suppressed. Although it often is not feasible to accomplish the necessary detection by means of LANDSAT data, great improvements are being made in this regard. Specifically: (1) the thermal infrared sensor that will be employed beginning with LANDSAT 3 will offer greatly improved opportunities for monitoring forest fires and (2) the comparative analysis of remote sensing data acquired sequentially (e.g. at 9-day intervals by means of the LANDSAT 1 and 2 vehicles operated in tandem) offers promise for the early detection of insect and disease problems in timber stands. In the above instances, as in the others described in this paper, the LANDSAT data must be made available quickly and in a form of sufficient quality to permit the necessary interpretations to be made.

B. Planning Rehabilitation Measures Following Damage to Timber Stands

Experience with LANDSAT-1 data has demonstrated the ability of such data, properly processed, to provide information needed in planning the rehabilitation of forest lands that have been damaged by fire or other agents. Often the need for obtaining such information promptly after the damage has occurred is exceedingly great in order that effective rehabilitation measures can be implemented at a reasonable cost. Specifically: (1) the time to reseed a forest burn is while there is still a "fluff" of ash on the burned area (i.e. before rain and wind can convert the area from a highly receptive seedbed to a very hostile one), and (2) the time to control insect and disease depredations is before the next generation of insects or pathogens can be produced in the already damaged trees and thus infest large numbers of nearby healthy trees.

C. Monitoring Range Readiness on Annual Grasslands

The Interior Department, primarily through its Bureau of Land Management, controls livestock grazing each year on millions of acres of annual grasslands. If, in any given year, grazing on these lands is permitted to occur before the annual grass species have matured their seed, there is a strong likelihood that few annuals will be present the following year. The result would, of course, be a tremendous decrease in animal carrying capacity of the rangeland, not only in that year but very likely for many years thereafter. On the other hand if, in any given year, the grazing on these lands is deferred until the annual grasses have dried out and lost most of their nutritive value, the grazing livestock may do very poorly. It follows that, each year, there is a requirement for monitoring the development of range grasses, area-by-area, throughout these vast annual grasslands, in order to determine the time of optimum range-readiness in each part of the

area. The distribution of grazing livestock can then be governed accordingly throughout the grazing season. The time of optimum range readiness on such lands varies markedly from year-to-year, depending upon the amount and distribution of moisture and on certain other climatic factors. Consequently LANDSAT data, properly enhanced and promptly made available for analysis, is of great potential value to the range manager.

2. AGRICULTURAL RESOURCES

A. Monitoring the Health and Vigor of Agricultural Crops

Although the damage done to timber stands by insects and pathogens can be very great, the damage which they inflict each year on agricultural crops is far greater. In many instances the key to reducing these losses, on agricultural crops, just as on timber stands, is early detection of the presence of the damaging organism so that control can be effected promptly in the infested areas before the insects or pathogens are allowed to reach epiphytotic proportions. Again it often is not feasible to accomplish the necessary detection by means of LANDSAT data. Great improvements in this detection capability are anticipated soon, however, as a result of improvements in spatial and spectral resolution that will be provided by the sensors that are to be mounted on future LANDSAT vehicles. For these potential improvements, like most of the previously mentioned ones, to be realized, however, there again is the need for LANDSAT data to be made available quickly and in a form of sufficient quality to permit the necessary interpretations to be made.

B. Monitoring Crop Development as an Aid in Crop Forecasting

Very substantial economic benefits can result if it is possible to forecast accurately the total production of each type of agricultural crop in a vast agricultural basin. In recent years, such great progress has been made in developing this capability through the proper use of LANDSAT data that many former skeptics are now looking forward to the time when crop forecasts in this country, and perhaps even on a global basis, might routinely be made through the use of LANDSAT data as the primary data input. For any given crop type, two components of inventory are involved: crop yield per unit area and crop acreage devoted to that type of crop. Total yield would be the product of these 2 factors. Because of the interest in this possibility, it is probable that every member of your Committee already is well aware of the acronym "LACIE" (for "Large Area Crop Inventory Experiment") which, beginning with the present growing season, will investigate on a very large scale the feasibility of making such crop forecasts, primarily through quick analysis of LANDSAT data.

3. MONITORING WATER RESOURCES

A. Water Supply Parameters

Something as mundane as a rainstorm can be a blessing or a curse depending on the amount of water flow that occurs from the watershed in a specified period of time, and in relation to the capacity of the channels in which the water must flow. Among the parameters that are of great significance in estimating the amount of water that will be yielded in a given period of time are (1) the total area of the watershed; (2) the amount of precipitation falling on each portion of it; (3) the degree of "wetness" of the soil (in each portion of the watershed) that already existed when the precipitation began to fall; and (4) where applicable, the areal extent, depth and water content of snow already present in each portion of the area. The dynamic nature of the events involved here is such that "real time" information, such as that obtainable from LANDSAT data, is far more valuable than information derived more accurately but over such a long period of time that it is too late to be relevant. Here, again, is a primary instance in which there is need for the analyst to be provided with LANDSAT data as promptly as possible after acquisition of the data by the LANDSAT sensors and in a form that is suitable for analysis. No inference is intended here that all of the above parameters are adequately estimated merely from the LANDSAT data, for this certainly is not the case. However, through comparative analysis of both multiband and multirate LANDSAT data, supplemented as necessary with limited amounts of ground data, the analyst is finding it possible to estimate water supply and probably water runoff values far more accurately than was heretofore possible within the same time constraints.

B. Water Demand Parameters

Mention already has been made, under the discussion of agricultural applications, of the fact that crop type and the rate of crop development often can best be monitored with the aid of LANDSAT data, promptly received and analyzed. Such analyses can readily be supplemented with ground observations as to the water requirements per unit field area, of each type of crop at each stage of its development. It follows that estimates of present water use and forecasts of near-future water demand can be accurately made with the aid of LANDSAT data. Since as much as 80 per cent of the total water demand commonly is for the growing of agricultural crops, this use of LANDSAT data potentially constitutes an important step toward our improving estimates in the future of the total water demand, area-by-area. The value of the forecasts of water demand diminishes, however, if a long period of time elapses between the acquisition of LANDSAT data and the analysis of such data. Consequently a justification exists in this instance, as in each of the previous ones, for making rapid estimates of the water demand of agricultural crops, area-by-area and season-by-season. This in turn emphasizes the requirement for

improved means of providing LANDSAT data to the analyst in a highly interpretable form and as promptly as possible.

What has just been said for agricultural demands for water can be applied with only slight modification to the demands placed on water supplies for industrial and domestic use. Thus it is seen that, by combining improved information regarding water supply (as discussed in the preceding section) with improved information on water demand, LANDSAT data can do much to improve our ability to manage water resources.

C. Water Transport Parameters

The ability of stream channels, canals and reservoirs to accomodate water supplies in specified amounts is a final aspect worthy of mention in the context of this discussion. The "monitoring" of reservoir levels, stream flow, and canal flow in relation to both the capacity of each to accomodate water and the need likely to be imposed on it as a result of various supply and demand factors, is yet another potentially important application of LANDSAT data, quickly processed and quickly analyzed. As in each of the other instances, we are imposing unnecessary requirements on a LANDSAT system, however, if we insist that this kind of information be provided solely from an analysis of LANDSAT data. Nevertheless, we already have progressed far enough in this area to be quite certain that the information desired can be more quickly and accurately obtained by using LANDSAT data to the fullest (and then providing supplemental data from other sources, as necessary) than if the entire effort were to be made without our using the LANDSAT data.

4. MONITORING SEA ICE CONDITIONS

There is general agreement that one of the major sources of petroleum products in the near future will be the area north of the Brooks Range in Alaska, bounded on the north by Prudhoe Bay and the Beaufort Sea. In at least 3 respects there is great interest in the possibility of accurately monitoring sea ice conditions in these northern waters on a "real time" basis: (1) in relation to the shipping of supplies into the area as necessary for large scale development of the oil fields; (2) in relation to the shipping of petroleum products out of the area by sea; and (3) in relation to the conduct and interpretation of seismic tests as necessary to make the oil drilling operations more efficient. As in the previous examples, there is great potential for using LANDSAT data as the primary data input in monitoring sea ice conditions in and around this area. The effectiveness of such data again depends, however, on the ability to provide the analyst with LANDSAT data promptly and in an adequately analyzable form.

5. CONCLUSION

If time were to permit, much more discussion could be given relative to the topic that was assigned to me for presentation today. Nevertheless the following conclusions seem warranted, even from the limited presentation that has now been made:

A. In virtually no case can we expect to obtain, entirely from an analysis of LANDSAT data, all of the information that is needed in order to better monitor and manage the natural resources that are of primary concern to the U.S. Department of Interior.

B. In virtually every case, however, we would do well to consider the likelihood that the information desired might better be obtained through the use of LANDSAT data in conjunction with various kinds of ancillary data than by any other means.

C. Because of the dynamic nature of most of the earth's natural resources, an ability to quickly monitor changes occurring in those resources, and thereby to react quickly with appropriate management measures is of paramount importance.

D. It follows from the foregoing that an aggregation of the individual requirements, resource type-by-resource type, for rapid processing of LANDSAT data results in a very sizable total requirement for our developing such a capability.

E. Even at the present time we know enough about how we could exploit a capability for the rapid analysis of LANDSAT data that we can predict cost-effective returns almost immediately from the expenditure of funds to develop such a capability at the EROS Data Center.

In view of the foregoing, I would like to be numbered among those who advocate to your Committee the appropriation of funds at the earliest possible date, for developing a capability at the EROS Data Center that will permit the rapid processing of LANDSAT data into products of sufficiently high quality to permit men and machines to extract from them information of great potential value in relation to the real-time management of natural resources. I join some very eminent colleagues in the remote sensing profession in making this recommendation. Furthermore I make the recommendation unequivocally, and despite the fact that (since it was not within my purview to do so), I have not described here the specific hardware developments that would be required to bring this capability into being. Suffice it to say in this regard that no great technological "break-through" would be required to bring about these developments. I also join my

colleagues in the assertion that the sooner these developments can be brought into being the sooner the dollar savings made possible by them can begin to be realized.

Your attention to my presentation on this very important topic has been greatly appreciated.

CHAPTER 10

SUMMARY

Robert N. Colwell

CHAPTER 10

SUMMARY

Robert N. Colwell

10.1.0 The following facts are emphasized in Chapter 1 of this progress report:

10.1.1 For a good many reasons, as indicated in the first portion of this chapter, the state of California continues to constitute an unusually favorable test site within which to conduct an integrated study of earth resources based on remote sensing techniques.

10.1.2 The findings from this research are proving to be of great potential significance both as an aid to the management of California's earth resources and also as a means for making similar remote sensing-based inventories to uniform standards on a global basis.

10.1.3 Research efforts under this integrated multi-campus study continue to be directed primarily toward developing remote sensing techniques for the inventory and management of California's water resources.

10.1.4 Studies pertaining to remote sensing in relation to water supply are concentrated on the Davis and Berkeley campuses in northern California. These campuses are nearest to the source of most of California's fresh water, viz., the northern Sierra Nevada Mountains.

10.1.5 Studies pertaining to remote sensing in relation to water demand are concentrated on the Santa Barbara and Riverside Campuses in Central and southern California; these campuses are nearest to the centers of demand for most of California's fresh water, viz., the San Joaquin Valley and the industrial and population centers of the Los Angeles basin.

10.1.6 The concepts embodied in this integrated remote sensing study of California's water resources, and the chronological plan being followed by each of the groups that are participating in it, will be found in Figures 1.1 and 1.2, respectively, of Chapter 1.

10.1.7 At the request of our NASA sponsors we have, in addition, made studies during the present reporting period relative to the cost-effectiveness of LANDSAT-1 data as an aid in the inventory of timber volume, timber stand condition class and timber growth rate.

10.1.8 To a greater extent than heretofore, the work of our Social Sciences group has been linked to that of our other remote sensing scientists to ascertain ways in which remote sensing data can cost-effectively enter into decision making processes relative to the management of California's earth resources.

10.2.1 As described in Chapter 2, during the present reporting period work performed by Ralph Algazi et al of the Davis campus has been concentrated on the application of remote sensing to the inventory and management of California's water resources, using the California Water Project as the primary example. In obtaining an overview of that project the Algazi group has brought to light the following pertinent facts:

- a. Water conservation problems do not constitute an operational constraint at the present time but they soon will.
- b. Water quality problems are rapidly increasing in importance particularly in relation to the proposed construction of the "Peripheral Canal" (which would by-pass the delta formed at the confluence of the Sacramento and San Joaquin rivers in the middle of the Great Central Valley of California) to facilitate the transport of vast quantities of northern California water to the southern part of the San Joaquin Valley and over the mountains to southern California. By eliminating the "flushing action" of these waters as they pass through the delta, this canal would seriously detract from both the water quality and the general environmental quality in the Delta area, according to some authorities while others violently disagree.
- c. Hydroelectric power has become a more important factor in California's economy as a result of the greatly aggravated energy crisis. In the short term, the generation of such power at Oroville Dam, and at other components of the California Water Project, has provided a significant economic benefit. In the long term, however, we must recognize that only a small fraction of the water entitlement of Southern California is now being delivered there. Since Northern California's water is only at an 800 foot elevation when it is at Lake Oroville, and since any such water destined for use in Southern California must be pumped to more than a 3000 foot elevation to be transported over the Tehachapi Mountains, the following serious aggravation of California's energy crisis is rapidly emerging: Instead of helping to provide California with much needed hydroelectric power, as at present, the California Water Project will constitute one of the biggest drains on such power in the near future, and by the year 2000 more than 3 times as much power will be needed to pump Southern California's share of this water over

the Techachipi Mountains as can be produced by the entire California Water Project.

10.2.2 In view of all of the foregoing factors, the Algazi group emphasizes that there is a continuing need to reassess periodically the objectives and the management of water resources in the State of California.

10.2.3 Consistent with the firm guidance given last year by the NASA monitors of our project, the Algazi group has made a study of the many different watershed models that are now being used operationally or which are given the most serious consideration in the technical literature. In attempting to make a quantitative assessment of the potential value of remote sensing in estimating water supply, this group then attempted to make an evaluation of the sensitivity of the most promising new models to various kinds of inputs and parameters. Results of their efforts in this regard appear in section 2.2a of this report. The two models receiving their greatest attention in this regard are (a) the Kentucky Watershed Model which makes some use of remote sensing data and (b) The California River Forecast Center (RFC) model which appears to lend itself very well to such use.

10.2.4 On the basis of this study the Algazi group concludes that the potential use of remote sensing in hydrologic models follows two possible lines:

- a. the estimation of soil moisture parameters for use in what are termed "lumped conceptual models"; and
- b. the derivation of spatial information on several water-supply-related parameters for use in what are termed "distributed conceptual models".

10.2.5 Having selected the California RFC model as worthy of intensive study, the Algazi group next sought to achieve two objectives by studying this model with the aid of the campus computer facilities at Davis:

- a. to study the sensitivity of the model to its primary parameters for the specific conditions which exist in the Sierra Nevada; and
- b. to simulate the effect on the operation of the model of those parameters which could be estimated by means of remote sensing. Results of this work are summarized in Figures 2.4a and 2.5a of this report.

10.2.6 Next, the Algazi group continued their studies, in cooperation with personnel of our Remote Sensing Research Program on the Berkeley Campus, relative to Snow Areal Mapping and Snow Modelling as aids to the estimation of basinwide snowmelt. They concluded that the following physical qualities are of prime importance in this regard:

(a) temperature field across the snowpack; (b) albedo (c) areal extent of the snowpack and (d) spatial distribution of snow and other forms of precipitation, especially in relation to topography (slope and aspect). On that basis, the group has undertaken a study to incorporate satellite data (e.g. from LANDSAT-1 and LANDSAT-2 in concert with NOAA-3 and NOAA-4) into models for the estimation of basin snowmelt. The status of that work is indicated in Figures 2.6a and 2.7a and in the accompanying text.

10.2.7 Based on these findings the Algazi group concludes that, whereas snowmelt models have been tested successfully by measurement of variables through the use of ground stations, many meteorological factors can exhibit large spatial and temporal variations even within a single basin or region. It is believed that most of these factors can best be evaluated in terms of time and space through the judicious use of remote-sensing-derived data. Hence the Algazi portion of this Progress Report concludes by describing a program that is designed both to verify this possibility and to result in the development of an operational procedure that will permit continuous computation of snowmelt on a regional basis.

10.2.8 The Algazi-Burgy group is undertaking an analysis of the manpower, time and cost factors that presently are involved in implementing both the Snow Surveys and the River Forecast Center water models currently being used in California. In relation to remote sensing possibilities, special attention is being given in these studies both to the critical periods when input data are needed and to a sensitivity analysis in relation to the "drivers."

10.2.9 The Algazi-Burgy group also is combining multispectral enhancement with ratioing (to reduce the effect of shadows in mountainous areas), masking of parts of the image, and the use of a likelihood ratio scheme in an effort to improve snow cover areal extent estimates. By such means the sensitivity of the estimate to a change in decision threshold has been made quite small (4% variation in areal extent for a 20% change in threshold).

10.2.10 The Algazi-Burgy group also is continuing its work on:

- a. application of remote sensing signal processing techniques to user oriented problems, and
- b. basic studies on signal processing algorithms pertinent to remote sensing applications.

10.2.11 The portions of the RSRP*work that are reported upon in Chapter 2b deal primarily with uses of remote sensing as an aid in estimating certain variables that are useful in predicting or measuring water supply. Specific activities and findings in this regard can be summarized as follows:

*Work done by personnel of the RSRP (Remote Sensing Research Program) on the Berkeley Campus is reported not only in Chapter 2b, but also in Chapters 6 and 9.

10.2.11.1 A multistage, multiphase sample design has been developed to relate basin water loss to snow water content, evapotranspiration, and pervious surfaces. These results are designed to allow improved watershed water supply estimates.

10.2.11.2 Levels of data used are:

- a. Digital and hardcopy satellite data
- b. Large scale (1:1000) color photography
- c. Ground data (several types)

10.2.11.3 Results to date with reference to the snow water content studies can be summarized as follows*:

- a. A weighted stratified double sample design utilizing hardcopy LANDSAT-1 and ground data was utilized in developmental studies for snow water content estimation.
- b. Results of this developmental study gave a correlation coefficient of 0.80 between LANDSAT sample units estimates of snow water content and ground subsamples.
- c. The preliminary study gave a basin snow water content estimate allowable error of 1.00 percent at the 99 percent confidence level with the same budget level utilized in conventional snow surveys.
- d. The snow water content estimate precision ratio was found to be up to 43 to 1 in favor of the preliminary basin snow water content estimation procedure over current estimation systems.
- e. The preliminary snow water content estimation system could reduce watershed snow water content estimation costs by 50 percent for the basin examined.
- f. Formulation of linear probabilistic (e.g. analysis of covariance) and physically realistic deterministic snow water content estimation models designed to refine estimates is proceeding.
- g. Techniques to refine sample unit specific LANDSAT-aided snow areal extent estimates utilized in snow water content estimation are developing. Present LANDSAT snow areal extent estimates, based on current RSRP methodologies, can be made with an allowable error of 5 percent at the 95 percent confidence level in April at the middle of the snow season for the Feather River Watershed. Direct

* The work reported in this section is considered to be complementary to, and not duplicative of, work currently being performed by NASA Goddard personnel under the title "GSFC Snow Mapping ASVT".

correlation of basin snow areal extent estimates with water runoff is also being considered.

10.2.11.4 Results to date with reference to evapotranspiration studies can be summarized as follows:

- a. Evapotranspiration estimation models currently in the literature have been evaluated for their utility in the multistage, multiphase sample design.
- b. Several evapotranspiration estimation models have been selected for efficient application at each level of information to be sampled.
- c. Techniques for developing data to check evapotranspiration estimates are being formulated.

10.2.11.5 Studies to date with reference to pervious surface water loss estimation have focused on estimation of total impervious surface area, which is related to pervious water loss by subtraction. Results to date can be summarized as follows:

- a. A preliminary area estimation procedure for impervious surface types of differing impermeability adjacent to stream channels has been developed.
- b. The preliminary technique employs a double sample of 1:125,000 color infrared highlight transparency data with ground or large scale photography.
- c. Impervious surface area estimates (related to pervious surface water loss by subtraction) can be specific to given subbasin areas as in the case of snow water content or evapotranspiration water loss estimation.
- d. A semi-automatic impervious surface estimation procedure to be employed in the context of the multistage, multiphase sample design has been outlined.

10.2.12 In attempting to summarize the work done by personnel of the Remote Sensing Research Program (RSRP) during the period covered by this report we must again emphasize the following fact as quoted from that part of our report: "Assessment of the performance of water yield models currently being used in California is a coordinated effort between the Davis (Algazi) and Berkeley (RSRP) NASA Grant groups". As suggested by the over-all title for our project, much of its potential strength is to be found in its integrated nature of which the cooperative Davis-Berkeley effort is a prime example. These 2 groups operate under the same basic hypothesis that "remote sensing data can provide a cost-effective means for obtaining a significant portion of the information needed for intensive water management".

Specifically, as previously indicated, personnel of the RSRP are seeking to develop timely, accurate, cost-effective procedures for estimating the amount of precipitation, the areal extent and water content of snow and the amount of evapotranspiration of each major component of a large watershed, such as that comprised by the Feather River (approximately 2.2 million acres or nearly one million hectares).

10.2.13 The basic approach to remote sensing-aided water yield estimation that is being used by RSRP involves a multistage sampling scheme, as previously stated. As for details of the step-wise procedure:

10.2.13.1 The first step involves a stratification of the water source area (through the use of LANDSAT and NOAA data) into basin or sub-basin areas of hydrologic significance. The use of topographic data to delineate elevational zones that are water-quantity related also is of importance in this step. By such means the pertinent vegetation, terrain and meteorological data components are combined in characterizing each basic resolution element, in this case the LANDSAT pixel.

10.2.13.2 Assuming, as in one representative case, that water loss is the variable of interest (in relation to water yield estimation) an estimate is next made of water loss for each pixel, based on the previously mentioned vegetation-terrain-meteorological data as correlated with limited amounts of historical data and ground truth observations.

10.2.13.3 Next a grouping of resolution elements into primary sample units (PSU's) is performed and a sample of these units is selected in each water loss-related stratum for further sampling. In this stage probability sampling usually is directed to areas of higher water loss. The chosen PSU's are then photographed from aircraft at medium and large scale. Photo interpretation of each medium scale photo within a selected PSU helps define a secondary sampling unit (SSU). The SSU's then form a series of large scale photo plots within each PSU centered at the medium scale photo center. The photographic SSU data, along with meteorological satellite data as calibrated from nearby snow-course and ground station data, provide the second level of information resolution.

10.2.13.4 Finally more detailed ground observations (e.g. of plant species, canopy geometry, etc.) are made for a sample of the photo SSU's to derive still more accurate water loss estimates. The estimate of water loss from the entire watershed, or from major components of it is made by expanding the ground data to SSU's, SSU data to PSU's, and the PSU data to the entire area of interest.

Thus, a cost-effective combination of an increasingly smaller sample of more precise and more expensive information levels is used to give basin wide estimates either of water loss (as in this case) or, with only slight modification, of any other hydrologic parameter that is best derived with the aid of remote sensing.

10.2.14 Procedures described in our previous progress reports for estimating timber volume were somewhat similar to the one just described for estimating water loss or water yield. There are 2 important differences, however.

- a. In estimating water loss or water yield spatial transforms must be developed to distribute coarsely defined information, such as meteorological satellite pixel data, and/or sparse point information to small resolution elements at a given information level, for example LANDSAT pixels; and
- b. the estimates may be needed much more quickly and at more frequent intervals. Consequently, there is a need for making real-time updates of variables that are important in estimating water loss and water yield.

10.2.15 Spatial transforms and real-time estimation techniques are discussed in detail by RSRP personnel in sections 2.522b and 2.523b, respectively, of this report, using evapotranspiration as a representative parameter.

10.2.16 We previously have indicated in this summary that, during the period covered by this report, personnel of RSRP have sought to develop remote sensing aided techniques not only for water loss estimation (as just described) but also for estimating watershed snow areal extent, snow water content, evapotranspiration and permeability of the earth's surface. Consequently, succeeding sections in Chapter 2b deal successively with

- a. manual approaches to snow areal extent estimation,
- b. semi-automatic snow areal extent estimation,
- c. manual and potentially semi-automatic impervious surface estimation,
- d. semi-automatic evapotranspiration estimation,
- e. preliminary meteorological satellite data work, and
- f. defining and evaluating the performance of current water supply models.

10.2.17 Appendices I and II of Chapter 2b document and evaluate evapotranspiration models in relation to possible remote sensing applications. Appendix III gives data collection instructions applicable to ground data needed for selected SSU's when the objective is water loss estimation, while Appendix IV gives similar data

collection instructions applicable to photo data needed for the selected SSU's.

10.2.18 Continuing work of the RSRP personnel at Berkeley involves:

- a. Documentation/development of procedures and software for water loss estimation.
 - b. Tests of water loss estimation model performance including cost-effectiveness analysis.
 - c. Tests and evaluation of improvement in Department of Water Resources water yield prediction models using remote sensing data as input.
 - d. Development of basin water/energy input estimation procedures including precipitation and temperature quantification based in part on LANDSAT and meteorological satellite data.
 - e. Interaction with California Department of Water Resources personnel concerning remote sensing-aided basin water loss quantification.
 - f. Investigation of the feasibility of performing remote sensing applicability studies for quantification of water quality in the Sacramento-San Joaquin Delta, a portion of the California Water Project transport area.
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10.3.0 In Chapter 3 of this Progress Report research activities performed under our integrated study by personnel of the Geography Remote Sensing Unit (GRSU) on the Santa Barbara campus of the University of California are described.

10.3.1 In keeping with our NASA-approved plan, GRSU, like its Riverside counterpart, concentrated on water demand problems, the better to complement rather than duplicate efforts of the Davis and Berkeley groups, which dealt with various water supply problems, as just described.

The three major fields of emphasis by the GRSU during the present reporting period were

- a. The development of remote sensing techniques for generating data needed in water demand models,
- b. The comparing of such techniques with conventional (ground-based) techniques in terms of time, cost and accuracy, and
- c. Consideration of the economic impact likely to result from acquiring better water demand information through the use of modern remote sensing techniques. GRSU has focused a major

portion of this research on evaluation of a hydrologic model currently being used by the Kern County Water Agency, which is the primary agency concerned with the use of water (mainly for agricultural purposes) in that vast area of the San Joaquin Valley of California known as Kern County. Throughout this report, as elsewhere, that model is referred to as the Kern County Water Agency (KCWA) hydrologic model.

10.3.2 Figure 3-2 presents the NASA-approved chronological plan that was to be followed by the GRSU, working cooperatively with the Riverside group, as they sought to develop improved means for assessing water demand through the use of modern remote sensing techniques. Items 4,5,6 and 7 are the four work items in that plan, as numbered in Figure 3-2, on which according to plan, personnel of the GRSU concentrated their efforts during the present reporting period.

10.3.3 A major effort was again effectively made by the GRSU personnel during this period to contact representatives from the various agencies having a direct and major interest in, and responsibility for, the coordination and planning for water supply, distribution and allocation.

10.3.3.1 Foremost among these are the previously mentioned Kern County Water Agency and the California Department of Water Resources. From the outset, and on a continuing basis, these agencies have played an important interactive role in the research activities of the GRSU. They have done so by detailing their current water resource activities, suggesting potential remote sensing applications providing "ground truth" data, and evaluating the potential usefulness of methodologies developed by the GRSU in relation to present and projected data requirements.

10.3.3.2 As detailed in Chapter 3, nine other agencies cooperated on an "as needed" basis to aid in the interpretation and definition of environmental parameters which they considered to be of primary importance in terms of hydrologic modeling.

10.3.4 Table 3-1 summarizes the various inputs needed in the hydrologic model for water demand that are to some significant degree derivable with the aid of remote sensing. As indicated by that table, the 6 most promising uses of remote sensing appear, (based on GRSU research during the present reporting period) to be

- detecting and obtaining the acreage of irrigated croplands
- identifying crop types,
- estimating soil moisture
- locating and analyzing perched water tables,
- assessing crop damage caused by present salinity conditions

predicting future salinity damage to crops based on known trends and careful image analysis.

10.3.5 The substantial progress made in each of the 6 areas listed in the previous section by GRSU personnel during the present reporting period is well documented in Chapter 3, and plans for furthering much of that work and bringing it to a definitive state of conclusion during the coming year are detailed in section 3.8.

10.3.6 By way of summarizing the major accomplishments of GRSU at the Santa Barbara campus this year it can be said that:

10.3.6.1 GRSU has demonstrated that the mapping of agricultural croplands can be done more cost-effectively in the San Joaquin Valley of California through the use of highflight photography and/or LANDSAT-1 imagery than by the various conventional techniques currently in use (viz., techniques used, respectively, in the surveys conducted by the California Department of Water Resources, in the yearly crop reports of the California Department of Agriculture, and in the crop reports compiled by individual water districts - 15 in Kern County alone).

10.3.6.2 Not only are the conventionally-produced reports more expensive and more time consuming than ones compiled by means of remote sensing, but collectively they also represent a large amount of duplicated effort by those preparing them. Such duplication could in large measure be avoided if crop land surveys based on remote sensing were to be implemented. All of the above three groups are much interested in this possibility. Quantitative data compiled by GRSU personnel in support of the conclusions cited above will be found in Chapter 3.

10.3.6.3 A sizable test, involving 4 water districts in Kern County, was undertaken by GRSU personnel to estimate the relative accuracies of cropland data derived from field observation, highflight photography and LANDSAT-1 imagery. Although some of the comparative data needed in order to complete this analysis are not yet available, it appears that agreement among the 3 methods to within 2 percent usually can be expected and that discrepancies greater than 3 percent will rarely be obtained, whether the remote sensing estimates are based on highflight photography, LANDSAT-1 imagery, or both.

10.3.6.4 It is anticipated that the best remote sensing based system for croplands mapping will be one that employs a multistage system involving LANDSAT-1, highflight photography, and very limited ground observation. The GRSU is currently in the process of devising and testing such a system.

10.3.6.5 The GRSU is also seeking to develop a procedure capable of cost-effectively utilizing remote sensing techniques to generate crop type data, on a nodal basis, as input to the hydrologic model currently being used by the Kern County Water Association (KCWA). The temporal nature of this task is such that multirate imagery of the type provided by LANDSAT-1 is highly desirable, and perhaps even essential.

10.3.6.6 The KCWA model pertains to an area of nearly 1 million acres (nearly 400,000 hectares), within which many different kinds of crops are grown. Consequently the area has been subdivided into "nodes" and efforts are being concentrated on achieving an acceptably high level of accuracy at the nodal level with respect to the informational requirements of the hydrologic model.

10.3.6.7 The Kern County area has salinity problems that are common to many arid environments. Because arid lands require a large amount of irrigation (up to 5 feet per year in Kern County) and because the irrigation waters contain soluble salts, the irrigation of such lands adds further to this problem, contributing as much as 25 tons of salt per acre per year. Unlike in humid climates these salts in the Kern County area are not leached downward into the ground water and eventually transported by streams into the oceans. The GRSU is investigating the usefulness of remote sensing techniques for the inventory and analysis of salinity problems in Kern County.

10.3.6.8 Additionally, in Kern County the ground basin transfer of salt-bearing waters away from higher lands raises the ground water level on the lower lands, often resulting in the perching of water tables or the temporary flooding of an area, especially if a subsurface impervious layer of soil known as an "aquaclude" is present. A major responsibility of the KCWA is to leach and drain these areas, as necessary, to improve productivity of the soil. In order to do this they must locate such problem areas as early as possible. One goal of the GRSU is to help KCWA accomplish this task.

10.3.6.9 In proceeding toward the above-mentioned goal, the GRSU has, during the period covered by this report, interpreted multirate Infrared Ektachrome highflight photography (scale 1/125,000) in selected areas as designated by KCWA. In so doing they have used the type and the vigor of both the native vegetation and the agricultural crops, area-by-area, as clues to the presence of troublesome salinity and perched water table conditions. Although quantitative comparisons of ground truth with these photo interpretations are not yet adequate, the GRSU concludes that it is "approaching an acceptable standard of accuracy in making such classifications from remote sensing imagery".

10.3.6.10 The GRSU is simultaneously conducting a study similar to the above but with the objective of detecting areas in which perched water is interfering with agricultural production. This entails comparing photo interpretation estimates with actual water table measurements made at 152 wells throughout the study area. In the coming months a determination will thus be made of the accuracies of interpreted delineations of perched water areas, based on such checking.

10.3.6.11 During recent months, GRSU participants in this integrated water resource study, have been working closely with farmers and with personnel of the Kern County Water Agency, in an effort to demonstrate that multirate remote sensing can be used cost-effectively to map areas in which crop production is being affected adversely by the above mentioned factors, (viz. (1) high soil salinity, (2) a perched water table, and (3) adverse seepage of water from one field to another). This effort is now being expanded with the result that interested individuals and agencies are assuming a major role in mapping such problem areas throughout the San Joaquin Valley.

10.3.7 This chapter concludes with an account of five separate special studies that the GRSU proposes also to be undertaken during the coming year, all of which involve the application of remote sensing in ways which the potential users of the results believe are of such promise that they are offering to support those projects: The projects are

10.3.7.1 the development of cropland mapping and crop identification techniques in coastal environments;

10.3.7.2 the making of ground basin permeability studies;

10.3.7.3 the detection and analysis of waterlogged soils;

10.3.7.4 the mapping of oil field sumps and roads; and

10.3.7.5 the making of forest fire fuel studies, cooperatively with personnel of the Remote Sensing Research Program on the Berkeley campus.

10.4.0 In Chapter 4, work performed on this integrated study by remote sensing scientists of the Riverside campus is described. As previously indicated their work continues to deal with uses of remote sensing to determine water demands and in this respect is complementary to but not duplicative of work done by personnel of the GRSU on the Santa Barbara campus. Specifically, the primary objective of Riverside's research effort during the period covered by this report has been to make optimal use of remote sensing in obtaining an accurate, up-to-date classification of land use in the upper Santa Ana River Drainage Basin of Southern California, the better to determine water demand in each portion of that large area. The Riverside group realized at the

outset that conventional, low-altitude aerial photography had long been used in that area as an aid to determining land use. As a result of their work during the present reporting period, however, it is now apparent that a very few high flight photographs, of the kind obtained by NASA's U-2 aircraft from an altitude of 65,000 feet, can replace a great many of these conventional aerial photographs and with far less distortion, thereby permitting the desired information to be obtained far more quickly and economically than was previously possible.

10.4.1 The Riverside group, like its counterparts in this integrated study from each of the other campuses, recognized the need for working closely with the potential user agencies. As applied to their studies, these agencies proved to be not only the California Department of Water Resources (DWR), but also that segment of the California Water Control Board that concerns itself primarily with the Santa Ana River Basin. In addition, the planning departments of the two concerned counties (Riverside and San Bernardino) expressed great interest in these studies and hence they also participated in planning and executing certain aspects of the research.

10.4.2 One important aspect of the Riverside group's research effort was the development of a machine overlay system which would permit updating and correlation of land use data in a form most useful for the local municipal water districts. An evaluation of that system by both the Riverside group and potential users of the system has led to the following conclusions:

10.4.2.1 Initial map preparation and conversion to machine code requires about the same number of man-hours as required for complete manual processing.

10.4.2.2 Cost-benefit ratios begin to improve significantly when, once in machine form, the data are analyzed, cross-correlated with ancillary data, used to produce statistics on acreage and population density as a function of land use class, and used to produce maps with various scales, color schemes and/or shadings.

10.4.2.3 Cost-benefit ratios will improve still more when updating procedures are performed. Thus it can now be reliably estimated that one such updating for the entire study area would require the expenditure of only 600 man-hours, using the machine oriented system, as compared with 6,000 man hours (a 10-fold difference) by the previously used system.

10.4.2.4 The minimum cost to a user agency for the hardware necessary to start using the machine oriented system would be only \$15,000.

10.4.3 The development of a Water Demand Model for the Upper Santa Ana River Drainage Basin has led the Riverside group to engage in each of the following four related studies:

10.4.3.1 development of a land use classification scheme that would be compatible with the detail discernible on "high flight" (U-2) photography;

10.4.3.2 development of the necessary correlations between the resulting land use classes and their corresponding water demands;

10.4.3.3 refining these correlations seasonally, especially in the agricultural lands so that seasonal as well as total annual water demands, area-by-area, could be taken into account by local water resource managers; and

10.4.3.4 development of a remote sensing assisted means of monitoring water quality in certain critical land use classes.

10.4.4 With respect to the last of the 4 items listed above, particular interest has centered on the land use class designated as "dairies", because disposal of both the solid waste and the waste water (including 47 gallons daily wash down water per cow), containing highly concentrated nitrates, is of steadily increasing concern.

10.4.5 With respect to each of the above-mentioned items, the research activities, accomplishments, and conclusions of the Riverside group during the period covered by this report are discussed in detail and well illustrated in Chapter 4. Among the highlights are the following:

10.4.5.1 Many of the vineyards in Southern California have become non-profitable operations due to high taxes, high labor costs and decreased demand for certain kinds of wine grapes. Since grapes grown in this area require approximately 0.26 hectare-meters (2.1 acre-feet) of water per season, the large scale abandonment of vineyards currently taking place in this area is having a significant effect on water demand. Hence the Riverside group is developing remote sensing-based methods for monitoring vineyard abandonment. It now appears that the season of photography will be a very important consideration in relation to this problem.

10.4.5.2 There is a need to use highlight photography to monitor water consumption, waste production and polluting effects on surface and subsurface water quality of the tremendous number of drylot dairies in the Chino Valley area of Southern California. Specifically, in this area there are 426 such dairies having a total cow population of 176,077 head. All of these areas have now been identified on highlight photography.

10.4.5.3 The California Water Quality Control Board is cooperating in this dairy study by furnishing information supplied by the dairymen on their individual operations (number and type of livestock, water use, waste production, waste disposal). Because of potential pollution problems, surface runoff from these dairies now is prohibited by the Santa Ana Regional Water Quality Control Board. Consequently dairymen must construct settling ponds, readily seen on the highlight photography.

10.4.5.4 It now appears that monitoring of these many dairy areas for compliance with the Board's directives can best be done with the aid of remote sensing. Investigations relative to this possibility are continuing with emphasis on measuring the cost-effectiveness of various remote sensing techniques.

10.4.5.5 As a result of the various efforts described above, participants in this integrated water resource study from the Riverside campus have convinced resource managers in Riverside and San Bernardino counties of the great value of remote sensing from LANDSAT-1 and U-2 aircraft for mapping (1) areas devoted to multi-cropping with consequent high water use; (2) areas devoted to dairying with special kinds of water use and associated nitrogen pollution of the soil; (3) fallow areas and areas of dryland agriculture having little or no water use; and (4) areas which, because they either are paved (e.g., streets and parking lots) or covered with buildings, contribute excessively high runoff during storms. The next step is to convert such convictions on the part of potential users into technology acceptance that will make them actual users. Progress of this type is being made as indicated below.

10.4.5.6 The California Department of Water Resources has announced that working with our Riverside group, it will base its forthcoming decennial inventory of the Santa Ana River watershed on these techniques. In addition, these techniques will be employed in the next few months by a private industrial group in mapping water resource factors in the western half of Riverside County.

10.4.6 The Riverside remote sensing scientists assert that the most important "drivers" of the water demand model are those involving agriculture. For this reason, they advocate early completion by their group of each of the following three agriculture-related studies in which they presently are engaged, using "high flight" color infrared photography as the primary data base:

10.4.6.1 early detection and monitoring of the abandonment of vineyards

10.4.6.2 identification of citrus orchards in relation to the extensive relocation of them that presently is occurring in the Riverside-San Bernardino area, and

10.4.6.3 differentiation between producing fields and fallow fields throughout the entire agricultural area of the Santa Ana River drainage basin, season by season, throughout the year.

10.4.7 The Riverside remote sensing scientists also wish to make several kinds of studies in the near future of California's coastal environment, basing these studies not only on U-2 photography but also on remote sensing data acquired from the various LANDSAT and NOAA satellites, where appropriate. Their interest in making such studies, like that of the GRSU in Santa Barbara, has been sparked, at least in part, by the recent assertion of the Director of California's Resources Agency to the following effect: Coastal zone remote sensing studies are long overdue in California because 80 percent of California's population lives in the coastal fringe. The proposed studies by the Riverside Group include:

10.4.7.1 coastal lagoon and marsh studies,

10.4.7.2 studies of the surf zone, including beach sand movement and changing beach morphology

10.4.7.3 studies of offshore areas that are sufficiently shallow to be analyzed with a recently developed water penetration film known as S0 224, and

10.4.7.4 identification of marine areas that are likely to be subjected to the hazards of oil spills, gas development or other factors associated with energy development, as per a request from the recently formed California Energy Commission. Details relative to each of these proposed studies appear in the concluding section of Chapter 4 viz. section 4.4. As with the work proposed by our remote sensing scientists on the other University of California campuses that are participating in this integrated study, the Riverside group considers it quite probable that some kind of contributory support will be provided by various potential user agencies.

10.5.0 Chapter 5 contains an account of work done by the Social Sciences Group. Activities of that group during the period covered by this report, and the rationale for those activities are summarized in the following sub-paragraphs.

10.5.1 The Social Sciences Group considers that its primary function is to ascertain the ways in which remote sensing-derived information can enter into decision-making processes, their costs and effectiveness, and their potential impact.

10.5.2 Within the California Water Project the focus of the Social Sciences Group has been to develop insights into the very complicated web of factors impinging on the management of water in order to understand how the new sources of information can be intelligently accommodated. Involved here are not only the official agencies at state, regional, county, and local levels, but also the relationships with federal bodies. All of these are part of an intricate combination of legal, cultural, historical, social, economic, and political events and trends.

10.5.3 Consistent with the above, the Social Sciences Group is in the process of trying to achieve two basic objectives:

10.5.3.1 to develop an understanding of the relevant social, political, and economic considerations that must be taken into account in the larger context of technological assessment, itself a matter of no small concern to agencies at all levels of government;

10.5.3.2 to ascertain the ways in which remote sensing-derived data can be put to beneficial use, specifically and primarily but not exclusively, in relation to California water.

10.5.4 The first of the above objectives (10.5.3.1) is a long-range matter. It is clear that technological advance is not achieved in a social, economic, and political vacuum; it is equally clear that decisions regarding public works must take into account the full dimensions of their impact. Hence the task of the Social Sciences Group is, in a sense, to "map the social landscape." This it has done in preparation for the next major step in the history of California water, viz., the Peripheral Canal. What can be said of this Group's ongoing work so far is that it represents an almost unique effort to accomplish something that is now just becoming recognized as essential -- the social assessment of public works.

10.5.5 With respect to the second objective (10.5.3.2) the Social Sciences Group has been working in close cooperation with our project's remote sensing specialists. In so doing, it has been (a) participating in a study to determine whether remote sensing can be cost-effectively integrated with data used at present in the California Cooperative Snow Surveys model, and has been (b) conducting a study to determine what environmental consequences will result from construction of the last remaining element of the California Water Project, viz., the Peripheral Canal. The potential significance of these studies lies in the application of a methodology for comparing different information-gathering technologies, an approach that could have more generalized applicability with respect to data acquisition for other natural resources.

10.5.6 During the period from July to November, 1974, the Social Sciences Group, in addition, made a number of advances to government agencies and agri-business groups to prepare the way for more applications of remote sensing techniques.

10.5.7 During the next several months the Social Sciences Group expects to complete its present study on the cost-effectiveness of various methods of snow surveying and initiate similar studies, some related to water, others to specific crops, and to examine the possible uses of the data in the various decision-making contexts.

10.5.8 With the greatly aroused interest of State legislative committees in scarce foods and resources in view of California's global role, the Social Sciences Group is finding that new sources of reliable data are taking on considerable significance in the eyes of California's resource managers. The Social Sciences Group has been able to establish excellent rapport with these managers and their associated agencies and expects to play an active role in these new relationships.

10.5.9 With the Peripheral Canal now the prime focus in the California water picture, environmental impacts in all their ramifications become ever more important. Through our numerous contacts with both advocates and adversaries, we have learned how urgent indeed is the need for constant monitoring of adverse effects that might result from construction of that canal. In this respect, remote sensing almost certainly will be found to be very useful. This being the case, the Social Sciences Group is now in an excellent position to ascertain the potential impact of such techniques on the decision-making processes.

10.5.10 Although reported in a separate chapter (Chapter 6), participation in the RSRP conducted work dealing with "Snow Survey Cost Effectiveness Analysis" represents a continuing activity of the Social Sciences Group. Like other activities in which this group is involved, the Snow Survey study seeks (1) to provide resource managers with useful research results and (2) to assess remote sensing technology in its wider applications.

10.6.0 Chapter 6 consists primarily of a comparative cost-effectiveness analysis of existing and LANDSAT-aided snow water content systems. Highlights of that analysis can be summarized as follows:

10.6.1 Cost Savings: Total estimated costs of the two production systems were compared at many levels of effectiveness. Figure 6.3 showed the CCSS system producing at a direct cost budget level of \$4,200 per snow survey month; point P₀ identified one production possibility at that budget. Point P₁, representing an output of equivalent precision and accuracy on the LANDSAT-aided system's production schedule, showed a \$2,300 cost savings. Extrapolated over the full range of survey months, this would imply a savings of around 50 percent (\$13,300) over the existing annual snow survey budget for the Feather River Basin.

10.6.2 Increased Precision:

10.6.2.1 Advantages of the LANDSAT-aided system are also apparent on the capability or effectiveness side. At a given budget level, the proposed remote sensing-aided snow water content estimation system produced results 4.9 times more precise than the existing system when stratum weighing option number 2 (W02) was applied. Under a different weighing option (W01), the LANDSAT-aided system was more than 1.8 times more precise than the current CCSS system when existing snow courses were stratified into snow water content strata based on LANDSAT data. Without this stratification, the LANDSAT-aided system (under W01) was 7.2 times more precise than the conventional approach. A comparison of weighing options showed that the LANDSAT-aided system under W01 estimated overall watershed snow water content with approximately 1.0 to 1.6 times the precision of the same system using W02.

10.6.2.2 The LANDSAT-aided system with weighing option 1 yielded the most precise estimates of total watershed snow water content. For a \$5,000 monthly budget, this approach estimated true basin snow water content to within $\pm 3.92\%$ ninety-five times out of a hundred. The precision of basin water content estimates could be improved still further by using techniques that increase the correlation of orbital-to-ground snow water content estimates. Smaller image sample units, more environment-specific snow class interpretations, and automatic processing of satellite digital data are some of the more promising of these techniques.

10.6.2.3 The choice between weighing options is dependent upon the researcher's objectives. W02 will give more precise estimates for fringe snow zone areas. If fringe areas are important during some periods of flood forecasting, then W02 with the LANDSAT-aided system will produce the better results. However, if overall basin snow water content is highly correlated with either short- or long-term water yield, then W01 is more appropriate.

10.6.3 Additional Abilities:

10.6.3.1 The LANDSAT snow areal extent-snow water content transform* presented here is only a first case model. Yet it yields correlations with ground sample data on the order of .80. More sophisticated stochastic and physical transform models now being developed should push this correlation significantly higher. The result will be greater snow water content estimation precision at the same level of budget.

10.6.3.2 The LANDSAT-to-ground correlation coefficient of .80 was achieved using satellite imagery specific to two ground survey dates plus minimal information from a third date. In an operational situation, however, detailed early-season and/or previous-snow-season LANDSAT data would be available in combination with the snow date of interest, this additional information should further increase the correlation coefficient and produce an even more cost-effective snow water content estimation.

10.6.3.3 A LANDSAT-aided snow water content estimation system offers several additional possibilities for future snow survey work:

- ° One byproduct of the LANDSAT-derived sample unit data is an in-place mapping of snow water content with respect to known melting environments and stream channels. Such time- and place-specific snow melt records could be used to aid in the selection of new snow course sites or in the placement of automatic snow sensors. Snow pack and stream channel juxtaposition data could also be used in refined models of runoff timing.
- ° Human and automatic analysis of daily meteorological satellite data, when correlated with less frequent LANDSAT and ground data, offers the possibility of extremely frequent watershed snow water content updating.

* The work reported in this section is considered to be complementary to, and not duplicative of, work currently being performed by NASA Goddard personnel under the title "GSFC Snow Mapping ASVT".

°Hydrologic models of the future will conceivably integrate remote-sensing and meteorological data with automatic ground-based snow sensing equipment. Real-time information eventually could be generated for entire watersheds or subbasins, depending on the need to assess the impact of a major storm or a minor subdivision. The continued refinement of remote sensing-aided snow water runoff estimation procedures is likely to be a necessary input into future water resource management practices.

10.7.0 In Chapter 7 an analysis is made of LANDSAT-type data as an aid in the making of a timber volume inventory. By way of summarizing that analysis, the following statements can be made:

10.7.1 A quasi-operational study demonstrated that timber inventories based on manual and automated analysis of LANDSAT-1 and supporting aircraft data could be made using multistage sampling.*

10.7.2 This inventory, using LANDSAT imagery for the first stage, proved to be a timely, cost-effective alternative to conventional timber inventory techniques in obtaining gross timber volume. The volume on the Quincy Ranger District (215,000 acres) of the Plumas National Forest was estimated to be 2.44 billion board feet with a sampling error of 8.2 percent. Costs per acre for the inventory procedure at 1.1 cent/acre compared favorably with the costs of a conventional inventory at 25 cents/acre. A point-by-point comparison of CALSCAN-classified LANDSAT data with human-interpreted low altitude photo plots indicated no significant differences in the overall classification accuracies.

10.7.3 The LANDSAT model was found to be a more efficient system of inventorying and therefore could replace the conventional design. As indicated in the text, the estimated cost-effectiveness ratio increased as the allowable error diminished. At a 10% AE, the benefit was 3.08:1 and at a 5% AE it was 3.56:1. This gain in efficiencies was largely the result of the following two main cost differences. (1) first stage procedures and (2) map generation. As to the first, in the conventional model the initial stratification of the area was done mainly by human interpreters using resource photography whereas in the LANDSAT model, operating on LANDSAT data, CALSCAN provided a point by point classification of the area at a lower cost and with greater precision. With this higher level of precision, coupled with the work done on large scale stereo triplets, a less costly sampling scheme was obtainable.

*

Technique development and testing for the LANDSAT-aided timber volume inventory were performed under Remote Sensing Research Program LANDSAT-1 studies funded by NASA contract no. NAS 5-21827, Task III, Investigation #217C. Comparative cost-effectiveness analysis, along with all other material in Chapter 7 not relating specifically to the LANDSAT-aided inventory procedure, was performed under this NASA grant's funding at the special request of the Office of Applications, NASA Headquarters.

As to the second difference, that of map generation, this study found that a WRIS black-and-white boundary map of a township at a scale of 4 inches to a mile could be processed by computer for approximately \$200. Using the LANDSAT model system, on the other hand a color-coded township map of the same scale could be processed for roughly \$50.

10.8.0 Chapter 8 consists of a cost-effectiveness comparison of existing and LANDSAT-based "total timber resources" inventory systems. Highlights of that analysis and related RSRP analyses can be summarized as follows*:

10.8.1 Numerous manual image interpretation tests were performed which were designed to evaluate various components of the LANDSAT-1 system. Detection of wildland resource features and conditions was done acceptably well on single-band, single-date LANDSAT imagery, but identification of the resources was more difficult. On a single-date color composite transparency, however, a skilled interpreter could detect and identify sixteen specific resource types 67 percent of the time and in broad types 73 percent of the time. In addition, tests showed that a three-band electronic enhancement and a two-band color composite were best among the image types tested for classifying commercial conifer forest.

10.8.2 A quasi-operational study was performed and demonstrated that LANDSAT-1 imagery is ideal for making vegetation/terrain type maps using manual interpretation techniques. In this demonstration project a vegetation/ terrain map was prepared from LANDSAT-1 imagery for the entire 2.25 million acre Feather River watershed and required only 11.5 hours of interpretation time. The LANDSAT-1 map had an accuracy level of 81 percent. A similar map made using conventional methods -- compiled from both current and outdated data -- had an accuracy level of 68 percent. Furthermore, the LANDSAT-1 map was prepared at approximately one-third the cost of the conventional map.

10.8.3 Using LANDSAT-1 imagery for the first stage in the sample design proved cost-effective in obtaining timber resource information compatible with USFS information requirements. Detailed summaries of volume information are still to be determined but correlations between ground plot measurements and photo plot estimates indicate the effectiveness of LANDSAT-1 imagery in estimating acreages of timber within stand type and in locating and collecting subsequent samples based on timber acreages. CALSCAN-classified LANDSAT data efficiently separated timber from non-timber classes and many of the timber classes may prove to be related to stand conditions as well as type. Transformation of LANDSAT-1 imagery to ground coordinate systems (e.g. UTM) was possible to within \pm a picture element when adequate control was provided. Costs per acre

* Technique development and testing for the LANDSAT-aided total timber resource inventory were performed under Remote Sensing Research Program LANDSAT-1 studies funded by NASA contract 5-21827, Task III, Investigation #317C. The comparative cost-effectiveness analysis, along with all other material in Chapter 8 not relating specifically to the LANDSAT-aided inventory procedure, was performed under this NASA grant's funding.

of the LANDSAT-based total timber resource inventory at 4.7¢/acre were slightly more than one-half the costs of a comparable USFS inventory system at 8.4¢/acre.

10.8.4 One of the greatest applications for analysis of LANDSAT-1 imagery is in the detection of changes in the resource base over time. For example, when using manual interpretation techniques, harvesting activities in the timbered regions of northern California could be monitored with LANDSAT-1 imagery. Also it was found that a determination of the location and an estimation of the size of a burned area could be made. LANDSAT-1 imagery provided the ability to accurately (1) map the perimeter of the burned area, (2) make an estimate of the acreage burned, and (3) determine the extent of damage within the fire perimeter. Other resource changes which can be monitored include: sediment plume size and direction, greening and drying of annual herbaceous vegetation, location and amount of irrigated crops, stage of development of marsh vegetation, and changes in the size of large ponds and lakes. For most of the changes that can be detected or monitored, supporting information from either aerial photographs or ground sampling is required in order to establish the significance of the change

10.8.5 The primary usefulness of vegetation/terrain map information derived from the LANDSAT-1 imagery in the North Coast is in the display of land use types throughout large regions. The LANDSAT-1 imagery provides a regional perspective of resource types and management units and allows the resource types to be evaluated in terms of their relationship to each other and related to the different types of land management practices. The LANDSAT imagery can be rectified and enlarged to a workable map scale of 1:250,000 or 1:125,000 thus providing a map base for resource types upon which other sources of map information can be superimposed.

10.9.0 Chapter 9 consists of six special studies closely related to this integrated multi-campus project, but not relating to the specific remote sensing applications envisaged by any of the participating groups:

10.9.1 The first of these four studies is entitled "Atmospheric Effects in Image Transfer" and reports on the work of two of our co-investigators on the Davis Campus, K. L. Coulson and R. L. Walraven. Highlights of that report can be summarized as follows:

10.9.1.1 Polarization of light from surfaces is a physical property that can be detected by remote sensing and used as an aid to the identification of certain types of earth resource features.

10.9.1.2 The most convenient means of using remote sensing to investigate polarization phenomena is through the use of a television display. By such means the signals are readily deciphered in terms of the physical quantities involved, and they can be introduced directly into a computer for digital enhancement or other manipulation of the data.

10.9.1.3 In order to check the concept of a video polarizer these members of our integrated team (viz. Coulson and Walraven) constructed a prototype system.

10.9.1.4 Despite the low resolution and excessive noise level of the system which they constructed these investigators found that it permitted both the intensity of polarization and the plane of polarization to be investigated either separately or in various combinations, including color displays (as seen on the television monitor's screen).

10.9.1.5 Results of this test have demonstrated that polarization adds a significant new element for potential use in discerning the unique "tone or color signatures" of various kinds of earth resource features, including those of significance in the inventory of water supply and demand factors.

10.9.1.6 In order to further develop the method of introducing polarization effects into remote sensing applications, improvements are greatly needed in the video polarizer system itself: The making of such improvements will constitute the principal efforts of these investigators during their concluding year of participation in our integrated study.

10.9.2 The second of the six special studies appearing in Chapter 9 is entitled "The Potential Usefulness of Earth Resources Technology Satellites in Relation to the Management of Earth Resources and the Preservation of Man's Environment." It consists of a report submitted by our project's Principal Investigator to the Congressional Committee on Aeronautics and Space Sciences on August 1, 1974. In it, many of the pertinent findings of research workers involved in our integrated study are summarized including the following:

10.9.2.1 Our research findings have repeatedly demonstrated that the great value of an ERTS^{*}mounted multispectral scanner is to be found, - not in any single attribute of such a remote sensing system, but in an unusually effective combination of attributes.

10.9.2.2 The eleven most important attributes of this remote sensing system, judging from work performed to date under our integrated study, are those listed in Table 1, on page 9-14 of this Progress Report.

10.8.2.3 This Special Study Report next presents a Table which summarizes the combination of characteristics of ERTS found to be most valuable in each of 5 "case studies" recently made by various participants in our integrated project.

10.9.2.4 The report continues with the presentation of details, in tabular form, relative to each of these 5 Case Studies.

10.9.2.5 The report concludes with a copy of the letter written to Senator Moss, (Chairman of the Committee on Aeronautics and Space Sciences) by our project's principal investigator inviting the attention of his committee to this important combination of ERTS-1 attributes, as documented in the fashion described above.

10.9.3 The third special study appearing in Chapter 9 consists of a statement made by our project's principal investigator before the Subcommittee on Space Science and Applications of the Congressional Committee on Science and Astronautics. Although this statement purposely avoids duplicating any significant part of the testimony given to the Senate Committee (Special Study No. 2) it nevertheless draws heavily upon the findings to date of research workers involved in our integrated study. Highlights of this statement can be summarized as follows:

10.9.3.1 The statement seeks to speak directly to certain specific questions as raised by personnel of the Office of Management and Budget, relative to the usefulness of ERTS^{*}.

10.9.3.2 Most of these questions, in turn, are based on adverse comments that were made only a short time after ERTS-1 had been launched, by each of three important potential users of ERTS-data, viz. the Statistical Reporting Service, the Forest Service and the Environmental Protection Agency.

* The term "ERTS" rather than "LANDSAT" is purposely used here to make the summary compatible with the published reports.

10.9.3.3 Among these specific questions, addressed in the principal investigator's statement, are the following:

10.9.3.3.1 Can ERTS-type data help improve crop forecasting systems?

10.9.3.3.2 Can ERTS-type data help improve forest inventories?

10.9.3.3.3 Can ERTS-type data help improve environmental analyses?

10.9.3.3.4 Is present ERTS technology good enough to justify commitment to an operational system now?

10.9.3.4 As indicated by the concluding portions of this part of Chapter 9, reactions by Congressmen to the above-described presentation and to our Integrated Study (on which much of the testimony was based) proved to be quite favorable.

10.9.4. The fourth of the six special studies appearing in Chapter 9 is entitled "Input Quality Encoding of Multispectral Data." It consists of a report submitted by one of our project's co-investigators, Dr. Ralph Algazi, at the 1974 Picture Coding Symposium which was held in Goslar, West Germany. Highlights of that report can be summarized as follows:

10.9.4.1 The quality acceptable in the encoding of multispectral data should be commensurate with the quality of the remote sensing input data.

10.9.4.2 Steps involved in the optimum encoding of such data (involving the use of a quantizer, a filter and a coder) are described.

10.9.4.3 An example is then given of how these steps can be implemented. The example is based on LANDSAT data of northern California currently under study by some of the participants in our integrated project.

10.9.4.4 The report concludes with an assessment of these results and a statement of plans for further work in this type of activity.

10.9.5 The fifth special study appearing in Chapter 9 is entitled "Utilization and Assessment of Remote Sensing Data". Written by Dr. Ida Hoos of our projects Social Sciences group, this article deals with the interface between remote sensing technology and the society which it seeks to serve. Among the points made in the article are the following:

10.9.5.1 Working in cooperation with other scientists, the social scientists should try to ascertain the social forces impinging on how and where remotely sensed data can enter into decision-making processes and how the data will ultimately affect the outcome of the decisions.

10.9.5.2 Herein may reside the vital link between the promise of remote sensing technology and its ultimate social significance.

10.9.5.3 Secretary Kissinger's comments about "rational planning for global production of food" (based in part on crop yield information derived by remote sensing) assumes that we live in the kind of a world in which such planning has some possibility of achievement. Hence Dr. Hoos examines this assumption from the standpoint of a social scientist.

10.9.5.4 In addressing the political and socio-economic aspects of water management in California, the Social Sciences group seeks to identify the real-life dimensions involved in decision-making, particularly, in the field of public policy formulation. The remainder of Dr. Hoos' special study develops this concept.

10.9.6 The sixth and last, of the special studies appearing in Chapter 9 consists of a statement recently made by the Principal Investigator of our Integrated Study, before the Interior Subcommittee of the Senate Appropriations Committee. The statement provides information, (based on certain of our findings under the integrated study) bearing on a Department of Interior's proposal. That proposal requests that funds be granted by the federal government for development of a capability at Interior's EROS Data Center for obtaining a "quick look" at high quality LANDSAT data.

A member of the Senate Committee hailed the statement comprising Special Studies No. 6 "unusually articulate and perceptive". Consequently the statement is soon to be reproduced in its entirety in the Senate portion of the Congressional Record.

At the time of this writing it is reported that, partly because of this testimony, prospects are exceedingly good that Congress will authorize

expenditure of the requested funds, amounting to several million dollars. If so, this will constitute a form of technology acceptance at a very important level and to an extent that probably could not be achieved without the presentation of convincing results, as obtained under our NASA-funded integrated study.

10.10 Overall summary

10.10.1 It will be apparent from the foregoing that work performed under our integrated study falls into 3 main categories.

10.10.1.1 Work designed to provide us with a better understanding of the factors at play, the premises involved, and "models" being used in the management of California's water resources.

10.10.1.2 Work designed to incorporate remote sensing technology cost-effectively either into the existing models or into modifications of them, the better to manage California's water resources (and also to manage certain other components of California's earth resources complex, such as timber).

10.10.1.3 Work designed to acquaint various federal, state and private resource managers and decision makers with our findings, so that they might better progress toward the acceptance of this new technology.

10.10.2 We believe that the balance which we are striving to achieve in conducting the three aspects of our study described above is a highly desirable one. Nevertheless, now that our study of the first of these aspects is nearing completion, it will be possible for the work which we propose to perform next year to be much more heavily oriented toward the second and third of these aspects, dealing respectively with determinations of cost effectiveness and with acceptance and adoption of the new technology by resource managers.